
IDA

INSTITUTE FOR DEFENSE ANALYSES

Assessment of Aviation Safety Concepts Phase I – Fighter Aircraft

T. L. Allen, Project Leader

April 2000

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OFFICE OF THE UNDER SECRETARY OF DEFENSE

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April 15, 2001

MEMORANDUM FOR: See Attachment 1

SUBJECT: Assessment of Aviation Safety Concepts, Phase One, Military Fighters

I have attached, for your information, a paper prepared by the Institute of Defense Analyses (IDA) assessing fighter aircraft safety concepts. OSD funded this project as a part of a larger project to improve military aviation safety.

In 1997, the Defense Science Board (DSB) recommended that the Department of Defense make zero aviation accidents its goal. To support that goal, the Deputy Under Secretary of Defense (Environmental Security) has been actively involved in identifying cost-effective approaches and technologies for improving military aviation safety. In addition to implementing specific DSB recommendations, this office initiated a detailed study of available and future technologies for fighter aircraft that could help the services meet their goals.

The IDA project reviewed a number of technologies and rank-ordered, by service and by aircraft, those which had the highest payback in terms of potential aircraft and aircrew saves, monetary losses avoided, and, factoring in the cost of each concept, total net benefit. The study highlights the value of an automatic ground collision avoidance system, not only for future fighters, but also for those aircraft with significant service life remaining. The study also recommends continued research on automatic midair collision avoidance technology as the next significant fighter mishap reduction capability. Results of the study were briefed to the Under Secretary of Defense for Acquisition, Technology, and Logistics in the summer of 2000.

We are pleased to bring this report to your attention and is currently supporting a detailed look at helicopter safety concepts, which should be available in July 2001. If you have any questions on the attached paper or any of the DUSD (ES) military safety programs, don't hesitate to contact me or Mr. Craig Schilder, my Safety Engineer, at (703) 604-1612 or by email at craig.schilder@osd.mil

Curtis M. Bowling
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2 Attachments:

1. Address List
2. IDA Paper, 12 April 2001



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INSTITUTE FOR DEFENSE ANALYSES

IDA Paper P-3524

Assessment of Aviation Safety Concepts

Phase I – Fighter Aircraft

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PREFACE

This paper provides the results of the first phase of an aviation safety study by the Institute for Defense Analyses (IDA) for the Deputy Under Secretary of Defense (Environmental Security). Following the completion of an analysis by IDA to investigate aviation safety technology options for the F-22A, IDA was asked to extend the methodology developed during that work to provide insight into safety concepts for all classes of military aircraft of all Services.

The IDA study team consisted of Dr. Thomas L. Allen (Project Leader), Dr. Kevin M. Eveker, Mr. Joshua A. Schwartz (Analyses Lead), Mr. Joseph W. Stahl (Cost Lead), and Dr. Lisa C. Veitch.

The team expresses its appreciation for the useful comments and constructive criticism provided by the IDA

Technical Review Committee chaired by Dr. David L. Randall and consisting of Gen Richard L. Craft, USAF (Ret.); Dr. William L. Greer; Dr. Richard J. Nelson; Dr. Jeffrey E. Schofield; and Mr. James P. Woolsey III. The team also benefited from discussions with Gen Bernard Randolph, USAF (Ret.) and Dr. Alan McLaughlin who helped shape the 1997 Defense Science Board findings on military aviation safety, as well as from meetings with a number of Air Force and Navy operational, technical, and safety personnel. In addition, without the support and helpful involvement of Mr. Curtis Bowling, the Assistant Deputy Under Secretary of Defense (Environmental Security) for Force Protection, this study would not have been possible.

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CONTENTS

EXECUTIVE SUMMARY	ES-1
DISCUSSION	1
History/Background.....	2
Methodology	12
Projected Flying Hours Remaining	14
Projected Attrition Remaining	16
Aircraft Monetary Values	18
Mishap Distribution By Cause	28
Safety System Concepts	58
Potential Aircrew Saved	60
Other Mishap Costs	66
Potential Net Benefit	70
General Observations	76
Safety System Summary	78
Recommendations	80

Appendixes

- A. Back-up Slides
- B. Glossary

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Over the past 50 years, the absolute number and rate of the military's most severe class of aviation mishaps have declined dramatically. But while the number of these Class-A mishaps has dropped from over 2,200 per year to 70 (and the rate per 100,000 flying hours has declined from 30 to 1.5), a 1997 Defense Science Board study pointed out that the mishap rate seems to have reached a plateau. To facilitate further mishap reduction, the Deputy Under Secretary of Defense (Environmental Security) requested that the Institute for Defense Analyses (IDA) investigate a broad range of aviation safety technologies and concepts. The purpose was to determine which of these have the greatest and most cost-effective potential for further reducing mishaps. This paper, which focuses on fighter aircraft, provides the results of the first phase of that study. It extends a methodology developed during a separate analysis of the F-22A that can be used to investigate safety concepts for all classes of military aircraft.

This study indicates that a number of concepts are cost-effective in the classic sense, since investment in safety technologies to improve the new Joint Strike Fighter (JSF), F-22A, and production F/A-18E/F aircraft mishap rates could be offset by reducing the production run by the number of aircraft saved. This would reduce overall investment in these programs with no net loss in numbers available or combat effectiveness. At the same time, even

for aircraft whose production runs are already complete, safety options are available whose value in terms of losses avoided comes close to equaling investment costs while saving significant numbers of aircraft and aircrew lives. This is particularly true for the Automatic Ground Collision Avoidance System (AGCAS) and for the Midair Collision Avoidance System (MCAS).

CAUSES OF MISHAPS

Over the course of the study, the IDA team collected data on current and future tactical fighter aircraft inventories, characteristics, flying hours, modification schedules, and costs. In addition, the team characterized the causes of fighter aircraft accidents and identified potential technological and human factor alternatives to redress them. Using data provided by the Service safety centers, IDA first determined the components of Class-A mishaps over the entire service life of each current aircraft through FY98. Figure ES-1 shows this distribution and number by cause for the five current USAF aircraft addressed in the study. The contribution of each of the five fighter types within each cause area is also displayed. The highest contributor to Class-A mishaps has been Engine Failure, accounting for 24 percent of all accidents, most of which are associated with the single-engine F-16. Additional contributors to major mishaps are Collision with Ground (primarily by the F-16 and A-10) at

23 percent, Midair Collisions (primarily by the F-16 and F-15A-D) at 16 percent, and Pilot Induced Control Loss at 11 percent. The F-15E and F-117 are hardly visible in the chart due to their relatively small number of mishaps when compared to the other aircraft. This means that concepts addressing only these two aircraft will not have a major impact on the overall mishap rate. Likewise, concepts aimed at resolving hydraulic or pneumatic problems, even if applied to all fighters, would have minimal impact on the overall number of Air Force fighter Class-A mishaps.

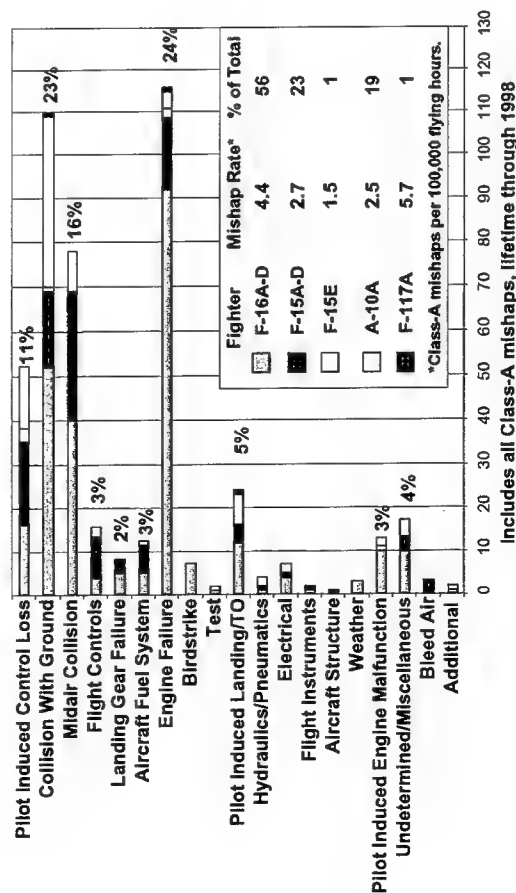


Figure ES-1. Air Force Fighter Class-A Mishap Distribution by Cause

ATTRITION PROJECTION

The IDA study team used these numbers not only to estimate remaining mishap rates for each of the current aircraft, but also to project future mishap rates for aircraft in production and development. Rates for the F/A-18E/F, JSF, and F-22A were calculated by considering each aircraft's mission, planned usage, and fundamental design differences. The team then used these baseline results to determine the potential mitigating effects of new technologies and concepts. Figure ES-2 shows the projected aircraft attrition remaining by year over the service life of the fighters addressed by the study. The chart indicates that there could be a significant payoff for incorporating appropriate technologies on the JSF, since for the nearly 2,000 of them that will be acquired and flown in the Air Force over the next half century, the projected lifetime losses (shown as aircraft attrition remaining) are estimated to be 302. Likewise, the Marine Corps is projected to lose 188 JSF aircraft over their service life and the Navy, 117. While new concepts could reduce the number of JSF losses, the charts also suggest a significant potential for avoiding mishaps (and associated aircraft and aircrew losses) by incorporating new technologies on the current fleet as well, particularly for those aircraft with high projected attrition remaining. Once a safety concept is proven, the charts suggest that the sooner it can be incorporated in the fleet, the greater the number of potential losses it can mitigate.

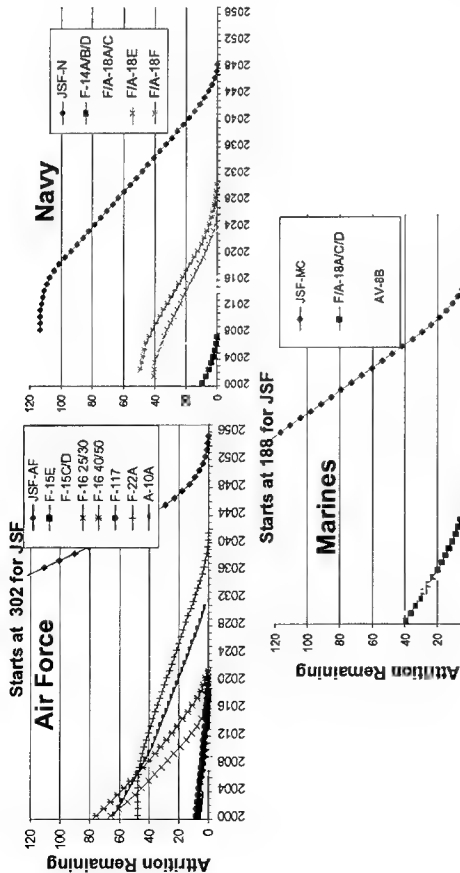


Figure ES-2. Projected Aircraft Attrition Remaining (No New Safety Systems)

MISHAP MITIGATION

Because the engine failure category was the highest contributor to fighter Class-A mishaps, IDA closely inspected the more detailed engine mishap data. For example, there were 62 instances of F-15/F-16 engine failures contributing to Class-A mishaps for those two aircraft in the FY89-FY98 timeframe. These mishaps came from seven different engine types across a wide variety of subcomponent areas. In fact, whenever the team found more than two incidents in a specific subregion, they noted the Air Force had already initiated a design change to help fix the problem. The team identified no major

comprehensive repair or new engine concept that could bring about a major reduction in the engine-related mishaps. Likewise, the team found no new training, organizational, or other human-factor related concepts that could be shown to significantly reduce mishaps. In the end, four concepts involving technological solutions were selected for more in-depth study. These are shown in Figure ES-3 and include AGCAS and MCAS as well as the Emergency Parafall Recovery System (EPRS), and the Pilot Activated Automatic Recovery System (PAARS).

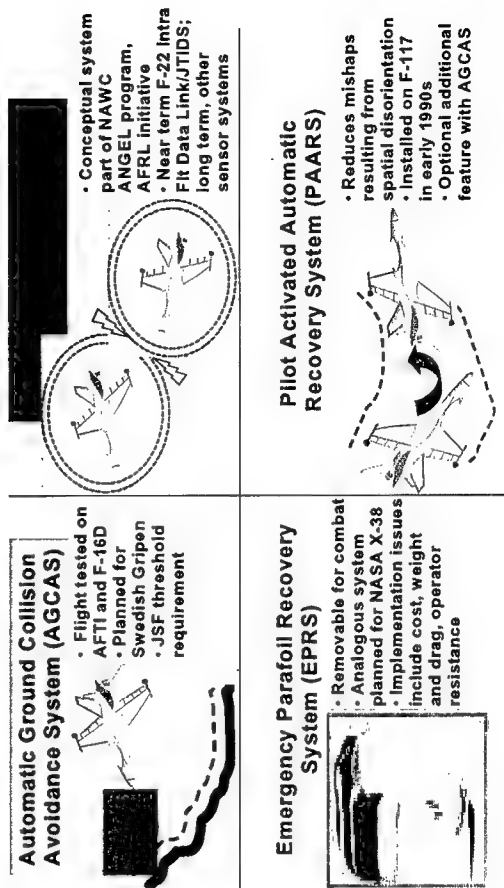


Figure ES-3. Concepts Selected for In-Depth Evaluation

MEASURES OF MERIT

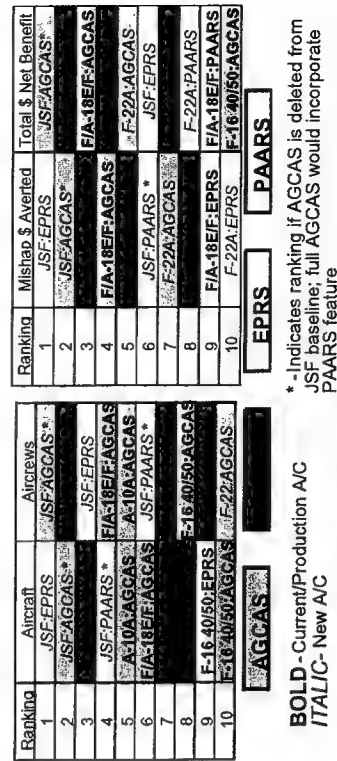
The effectiveness of these systems was calculated by determining the potential effect of each system for each fighter aircraft studied across a series of pertinent measures. These included potential mishaps averted, aircrew lives potentially saved, mishap costs avoided, and total monetary net benefit. The team calculated total monetary net benefit by first adding the value associated with averting mishaps using Service-published flyaway costs for lost aircraft, \$10 million for each lost aircrew, and \$1 million for all other losses associated with each mishap. From this, the total estimated Engineering and Manufacturing Development (EMD), production, and operations and support (O&S) costs of the new concept were subtracted. These costs ranged from less than \$70 million for PAARS on the F/A-18A/C to over \$3.5 billion for EPRS on the Air Force JSF fleet.

The specifics of calculating total monetary net benefit can be illustrated using AGCAS. For example, the EMD, production, and O&S costs associated with installing AGCAS on the digital F-16 Block 40/50 were estimated by IDA to be \$244 million. After a nominal 3-year EMD period and a 6-year fielding plan completed in 2010, AGCAS would then be projected to save eight F-16s and six aircrew over the aircraft's remaining service life. An Air Force estimated \$19 million flyaway value of that aircraft, \$10 million for each replacement pilot's training, and the \$1 million estimated for other costs per Class-A

mishap generate a total cost avoidance for AGCAS on the Block 40/50 F-16 of \$210 million. This is \$34 million less than the \$244 million cost, given the dollar assumptions and estimates used in this study. Similar calculations generate \$331 million over breakeven for the F-22 (\$171 million cost for the AGCAS system, \$502 million in value protected), \$393 million for the F/A-18E/F (\$278 million in AGCAS system costs and \$671 in mishap costs avoided), and \$3,800 million for the Joint Strike Fighter.

FINDINGS

Figure ES-4 summarizes the results for all four measures over the four systems investigated. JSF dominates the top-10 rankings for both aircraft and aircrews potentially saved. AGCAS is currently included in the JSF Joint



- Although JSF dominates rankings, A-10, F/A-18E/F, F-16 Block 40/50 & F-22 options have significant potential for saving aircraft and crews
- Positive net benefit for JSF, F-22 options as well as F/A-18E/F
- Highest ranked nearest term option is AGCAS on F/A-18 and F-16

Figure ES-4. Safety Concept Measures of Effectiveness

Operational Requirements Document and is expected to be fielded on the initial production aircraft. If this were not the case, the results show that AGCAS on the JSF would be ranked second in potential aircraft saved and first in potential aircrew saved. Although safety systems on new aircraft dominate the rankings, the chart also indicates that some safety systems on selected current aircraft could also potentially save a significant number of aircraft and aircrew lives, even allowing for the normal delays associated with completing EMD and initiating production. In particular, AGCAS on the A-10 and F-16 Block 40/50, and AGCAS and MCAS on the F/A-18E/F have a significant potential for saving aircraft and aircrews.

Likewise new aircraft dominate the other measures, with AGCAS and MCAS appearing to be the most cost-averting, highest monetary net benefit options. The F-16 Block 40/50 also appears in the top 10 of the total net monetary benefit rankings. Although slightly negative in terms of overall monetary net benefit, it is the highest ranked of those aircraft no longer in production and could have the earliest impact on aircraft and aircrew mishap reduction.

OBSERVATIONS

The results provide a solid basis for retaining AGCAS as a threshold requirement for the JSF. In addition, AGCAS on both the F-22A and the F/A-18E/F offers an overall net positive benefit and is close to the break-even point if incorporated in the F-16 and F/A-18A/D. Installing AGCAS on F-16 Block 40/50 provides the earliest opportunity to reduce Class-A mishaps and confirm system effectiveness, enable more accurate cost estimation, and develop operator buy-in before the system is extended to other fighters. Investment in MCAS technology development also appears merited, while the high estimated costs of EPRS suggests the system needs more study before implementation is seriously considered. Finally, the study indicates that PAARS does not provide sufficient mishap avoidance to yield positive net benefit as a stand-alone program, despite its low cost.

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DISCUSSION

Over the past half century, the overall Class-A¹ mishap rate for all fixed-wing and rotary-wing military aviation has decreased dramatically. From over 2200 major military aviation mishaps and a Class-A mishap rate approaching 50 for every 100,000 hours of flying time in 1955, the number of major accidents has declined to 70 last year with a corresponding rate of 1.56 per 100,000 flying hours.

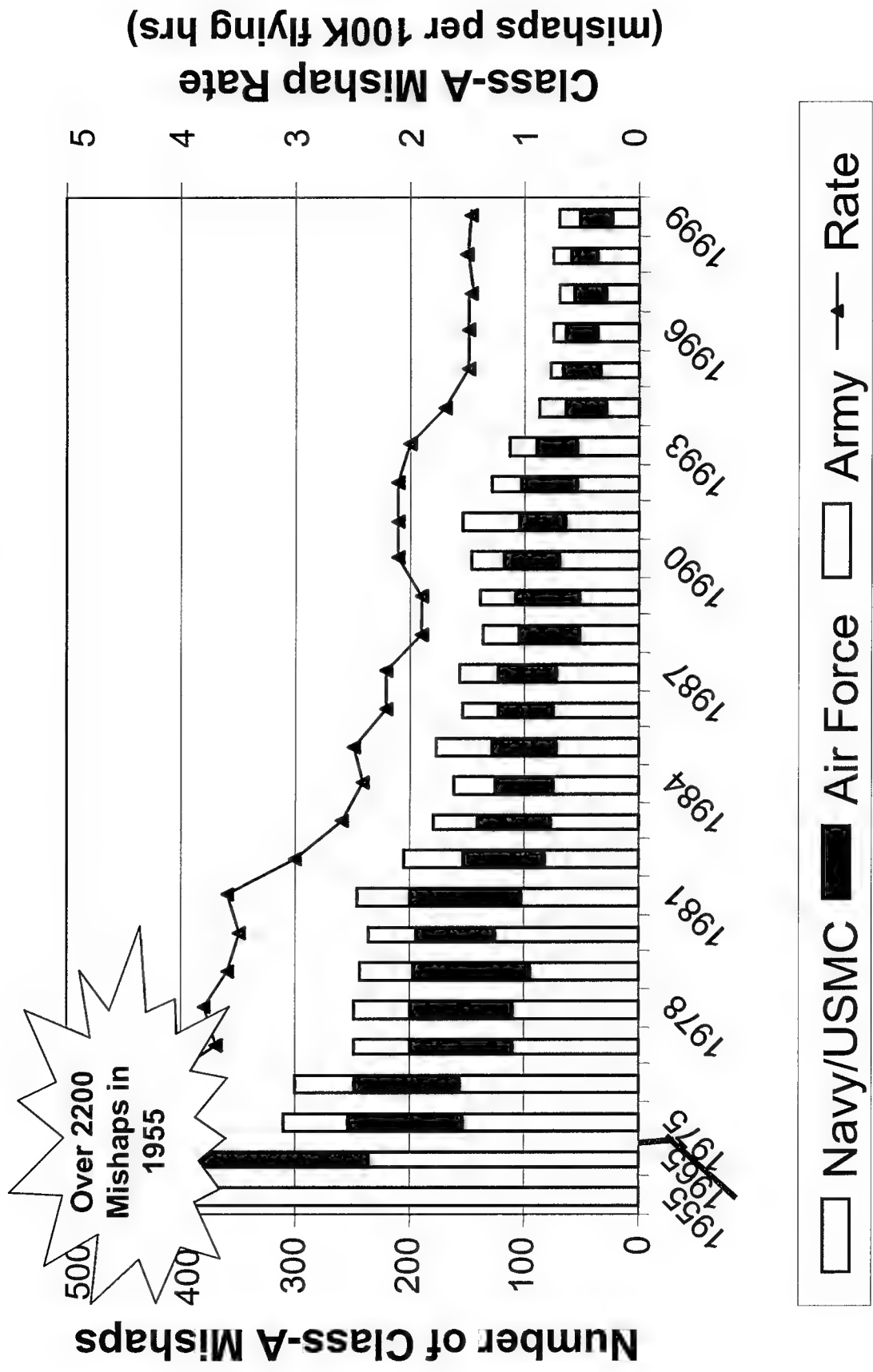
A reduction of this magnitude is a result of a number of important factors. Aircraft are much more reliable today than they were in the 1950s. Aircrew and maintenance personnel alike have benefited from a number of technological improvements ranging from built-in tests and monitoring systems to improved system and aircraft design. Aircrew and maintenance personnel are far better trained and supported, while on-board systems provide real-time input on aircraft and engine health and closeness to G and stall limits. In-flight recorders and monitors allow maintenance and supervisory personnel to determine when aircraft limits have been exceeded and when special inspections are required due to excessive stress on aircraft components or because of nonstandard temperature readings or particulate levels in the aircraft's engine oil. Improved runway surfaces, aircraft carriers, carrier

¹ The Class-A mishap rate is a measure of the most serious aircraft accidents involving loss of life or permanent disability on the part of the humans involved or else loss of aircraft or more than \$1 million in damage with respect to the equipment. Definitions for Class A, B, and C mishaps are included on a back-up slide in Appendix A.

design, and other ground-based navigational systems have also enhanced the operating environment. Modernized instructional techniques, the availability of realistic simulations and simulators, and real-time computer support to the maintenance force all help to improve performance and ensure that maintenance and logistics actions are taken in a way that reduces risk and enhances aircraft health and safety. The understanding of flight physiology has also improved through time and with it the systems needed to help reduce hypoxia, G-induced Loss of Consciousness (GLOC) and other conditions that contributed to the high accident rates of the past. Today's fighters are the best designed and safest in history.

At the same time, after nearly 40 years of steady improvement, the reduction in the Class-A mishap rate may be leveling off. In fact, some officials are concerned that the numbers are not just stagnant, but may be about to reverse. They point out that the percentage of experienced aircrew, maintenance personnel, and supervisors has dropped significantly over the past few years. At the same time, the operations and personnel tempos are much higher than normal peacetime rates while the supported missions have shifted from demanding and experience-building training scenarios to more benign high-altitude combat air patrols associated with peacekeeping. This could lead to complacency and a tendency to cut corners in mission preparation and execution, a deadly combination particularly if accompanied by a return to the more challenging missions.

Aviation Class-A Mishap History



In 1997, a Defense Science Board chaired by Air Force General (retired) Bernard Randolph conducted a broad study of military aviation and took note of the military aviation safety trends discussed on the previous page. While the Board applauded the significant reductions in accidents and the mishap rate over the past several decades, they also noted that despite these improvements, over a billion dollars and 100 lives continue to be lost each year due to aviation mishaps. In addition, the Board noted the previously declining Department of Defense aviation accident rates had reached a plateau. Given the increasing monetary, human, and political costs associated with mishaps, safety-related technologies that are already available, and the long-term potential for additional improvements in aviation safety and training, the Board recommended the Department develop plans to work toward a goal of zero Class-A mishaps.² The Board made a number of recommendations to assist in this effort.

Following the implementation of many these policy-related recommendations and in the absence of Service agreement on a clear Class-A mishap objective, the Office of the Deputy Under Secretary of Defense (Environmental Security) [DUSD(ES)] requested the Institute for Defense Analyses (IDA) to explore a broad range of aviation safety alternatives in July 1999. At that point, IDA was in the process of completing a focused study on safety technologies for the F-22A. Conducting such a study for new aircraft is a recent requirement levied

² As a point of comparison, the U.S. commercial airline industry has experienced an accident rate (where at least one fatality occurred) of less than 0.10 per 100,000 flying hours over the past 20 years.

by the Department, and in this case the policy resulted in a number of concepts being analyzed in detail with respect to their potential cost and effectiveness for the F-22.³ A major finding was that the Automatic Ground Collision Avoidance System (AGCAS) can be implemented on the F-22 to save aircraft and aircrew over the life of the aircraft. In addition, even conservative estimates suggest that since the mishaps avoided would increase the total number of F-22s available, a small decrease in production could be implemented. Thus AGCAS saves more than its costs in constant dollar terms with no change to the pre-AGCAS fleet size or combat capability.

DUSD(ES) requested that IDA expand the methodology used for the F-22 study to conduct a broad area review of potential safety concepts, including new technology, human factors research, and new organizational concepts. Because at the time the fighter force had witnessed a number of high-profile mishaps, the sponsor directed that IDA begin with that part of the military aviation force structure. If the methodology could be successfully expanded to the fighter aircraft of the Air Force, Navy, and Marine Corps, then DUSD(ES) planned to support additional research into the other components of military aviation. Because resources were limited, research team objectives were to provide high level rank ordering of potential fighter/safety concept combinations to help focus Service and DoD policy and future military aviation safety investments.

³ The results of that study are detailed in IDA paper IDA P-3487, *Costs and Benefits of the Installation of Certain Flight Safety Systems on the F-22A Aircraft*, October 1999, UNCLASSIFIED.

Background

- 1997 DSB Aviation Safety Study:
 - Indicated that despite reduced mishaps rates and flying hours, over \$1B in assets and 100 lives are lost each year due to aviation mishaps
 - Noted that the previously declining DoD aviation accident rate had leveled off
 - Recommended that DoD develop plans to work toward a goal of zero Class-A Mishaps
- In July 1999 DUSD(ES) requested IDA to explore aviation safety alternatives

This chart lays out the objectives of the Aviation Safety Concepts Study. Beginning first with the fighter force, the study team focused on investigating and assessing the life-cycle costs and benefits of a wide range of new concepts aimed at reducing the Class-A mishap rate. The concepts include investments in flight-safety-related technologies as well as changes in Service policies, processes, and priorities that might impact causes from human factors. The study team was given broad latitude to explore all aspects of training, maintenance, or operations and to select alternatives that if applied to specific military aircraft could reduce the life-cycle cost of the system by measurably reducing the number of aircraft and aircrew lost to accidents.

While the major scope limitation for this phase of the effort was the focus on fighter aircraft, the resources available imposed a practical constraint by limiting the amount of detailed investigation time that could be conducted on the various concepts. Consequently, the study was designed to collect and review data at a high level in order to focus on only those options that appeared to have the highest payoff, both in terms of

reducing the loss of aircraft and aircrew, and in terms of feasible budget expenditures. Alternatives that required extensive investment in a specific type of aircraft with the potential to impact only a small number of future projected mishaps were quickly screened out, as were other concepts that appeared sensible on the surface but for which no quantifiable improvement in the mishap rate could be estimated. In addition, the sponsor asked the study team not just to determine the highest payoff concepts, which might have led to a bias in favor of technologies for future systems, where the cost of reducing mishaps can be offset by smaller production runs, but also to look at systems on current aircraft whose production lines are already closed, and therefore offer no savings from reduced production.

In the end the study reviewed approximately 40 concepts and provided detailed analysis on 4 that appeared to have the potential for significant impact on the mishap rate. The approach not only helped investigate safety alternatives for the fighter force but is also extendible to other classes of military aircraft.

Objectives and Scope

- Investigate and assess the life-cycle costs and benefits of potential flight-safety-related investments and changes in Service policies, processes, and priorities for military aircraft in order to:
 - Determine if there are investments in technologies or training, maintenance or operations, that if applied to specific military aircraft, would reduce the life-cycle cost of the system by reducing the number of aircraft and crew lost to accidents
 - Identify alternative strategies that will impact aircraft attrition and life-cycle costs
- Begin with fighter aircraft and, as resources allow, extend methodology to rotary-wing and other aircraft

This chart outlines the methodology used in the study. The Air Force Safety Center provided detailed information on A-10, F-15, F-16, and F-117 Class-A mishaps, while the Navy Safety Center provided similar records on the AV-8, F-14, and F/A-18. The study team thoroughly reviewed the data, analyzed historical trends, and identified broad components of attrition for each fighter. They also extended the methodology to estimate attrition rates for future F-22 and the Joint Strike Fighter (JSF) aircraft for each Service based on expected mission profiles and design performance parameters. In examining attrition, the team noted that the Services have different taxonomies for determining mishap causes (the Air Force provides more cause categories while Service-unique definitions cause some mishaps to be categorized differently by the two Services). Since the study's methodology required analysis of each specific mishap to determine the expected mitigating impacts of each concept, these taxonomy differences did not impact the results.

Once the components of attrition were identified, the team reviewed a number of technological and human-factor-related concepts designed to reduce the Class-A mishap rates. In keeping with the high-level nature of the study and because of the large potential error bounds associated with cause and effect in the human effects arena (and the fact that detailed comparative data to contrast mishap aircrew with their peer groups were not available), the team elected to pursue human factor solutions only if

preliminary screening suggested specific concepts that would provide similar order of magnitude benefits to those associated with the leading technology alternatives.

For those concepts that appeared to have the highest payoff, the team then projected benefits based on the ability of a concept to mitigate various types and classes of mishaps on each aircraft individually. The team also used the best available cost, technology, and implementation schedule projections available to not only determine the cost avoidance associated with reduced mishaps, but also to estimate the cost of implementing each concept. In particular, the value of an aircraft saved or a mishap avoided became a key aspect of the study, since in the end these values were the basis for determining net benefit rankings. The study looked at both near and far term solutions, but only those for which an engineering solution for a specific technology approach was at least postulated. For example, new materials that could absorb a high speed collision with no damage to the aircraft were not investigated since there is no current actionable theory or engineering solution available for producing such materials.

Once the overall methodology has been proven useful in investigating safety concepts for fighters, it will be available for application on other aircraft such as helicopters, trainers, and large transport aircraft to help select high payoff mishap reducing options for them.

Methodology Overview

- **Analyze historical Class-A mishap data for tactical USAF, USN, and USMC fighters**
 - **Identify components of attrition**
- **Identify applicable fighter safety technology concepts to reduce Class-A mishaps**
 - **Identify human factors options if able**
- **Analyze available cost-benefit measures for installing technology options for specific aircraft**
 - **Consider near and far term**
 - **Analyze human factors options if resources allow**
- **Apply same methodology to other aviation components**

This chart displays the measures of effectiveness (MOEs) used to rate the safety concepts evaluated in the study. The team selected the MOEs by considering metrics that are both meaningful and quantifiable. In the end, five measures are used to describe the potential impact of the various safety concepts. For each MOE, the study calculated absolute values and then rank-ordered the aircraft/safety concept combinations starting with the one with the largest projected impact in terms of the measure. The study assumed that the selected technology could be implemented as intended on each of the fighter aircraft; it did not evaluate the relative risks of successful implementation of the systems on each aircraft.

The first two MOEs provide an estimate of the number of aircraft and aircrew that could be saved over the remaining service life by implementing a specific safety system on that aircraft. The number of aircraft saved measure represents those aircraft that would otherwise have been destroyed without the implementation of the new concept. The number of aircrew saved measures the number of aircrew fatalities or permanent disabilities avoided as a result of implementing the concept.

The next two MOEs involve calculating a monetary value of the aircraft saved and a total monetary value of mishaps averted as a result of implementing a specific safety system on each aircraft. The total monetary value of the mishaps avoided includes the estimate for the aircraft value, as well as for aircrew losses avoided (for permanent disability and fatalities only) and the value of avoiding other associated mishap costs (such as the cost of mishap investigation and aircraft recovery). For the baseline calculations, aircraft value was not depreciated over time. The rationale for this approach to depreciation will be discussed in detail later. As an excursion, the study did examine the effects of depreciation; those results are included in Appendix A.

The last MOE is the estimated net monetary benefit of installing a specific safety system on a designated aircraft. This measure is determined by subtracting the total cost of implementing the system on each fighter [including engineering and manufacturing development (EMD), production, and operations and support (O&S)] from the total value of the mishaps averted. The baseline for net benefit assumes a fixed aircraft value (no depreciation) over time. The effect of depreciating aircraft value is provided in Appendix A.

Measures of Effectiveness

- Number of Aircraft and Aircrew Saved
- Monetary Value of Aircraft Saved and Mishaps Averted
 - Value of potential aircraft saved
 - Value of aircrew losses precluded
 - Value of avoiding other mishap-related losses and activities
- Net Dollar Benefit (value of mishaps averted - concept cost)
 - Concept cost includes EMD, production and O&S

Concepts ranked in terms of largest potential impact on MOEs*

***Relative risks of implementation not evaluated**

This chart captures the verbal description of the previous three charts in a pictorial format. IDA first collected total aircraft inventory (TAI) and primary mission aircraft inventory (PMAI) data from each Service by aircraft type. Based on historical data, figures provided by each Service's Program Objective Memorandum (POM), and published planning factors, IDA calculated the projected total aircraft flying hours for each aircraft by year through the expected service life of each fighter. This data was then converted to show the total flying hours remaining by fighter and by year.

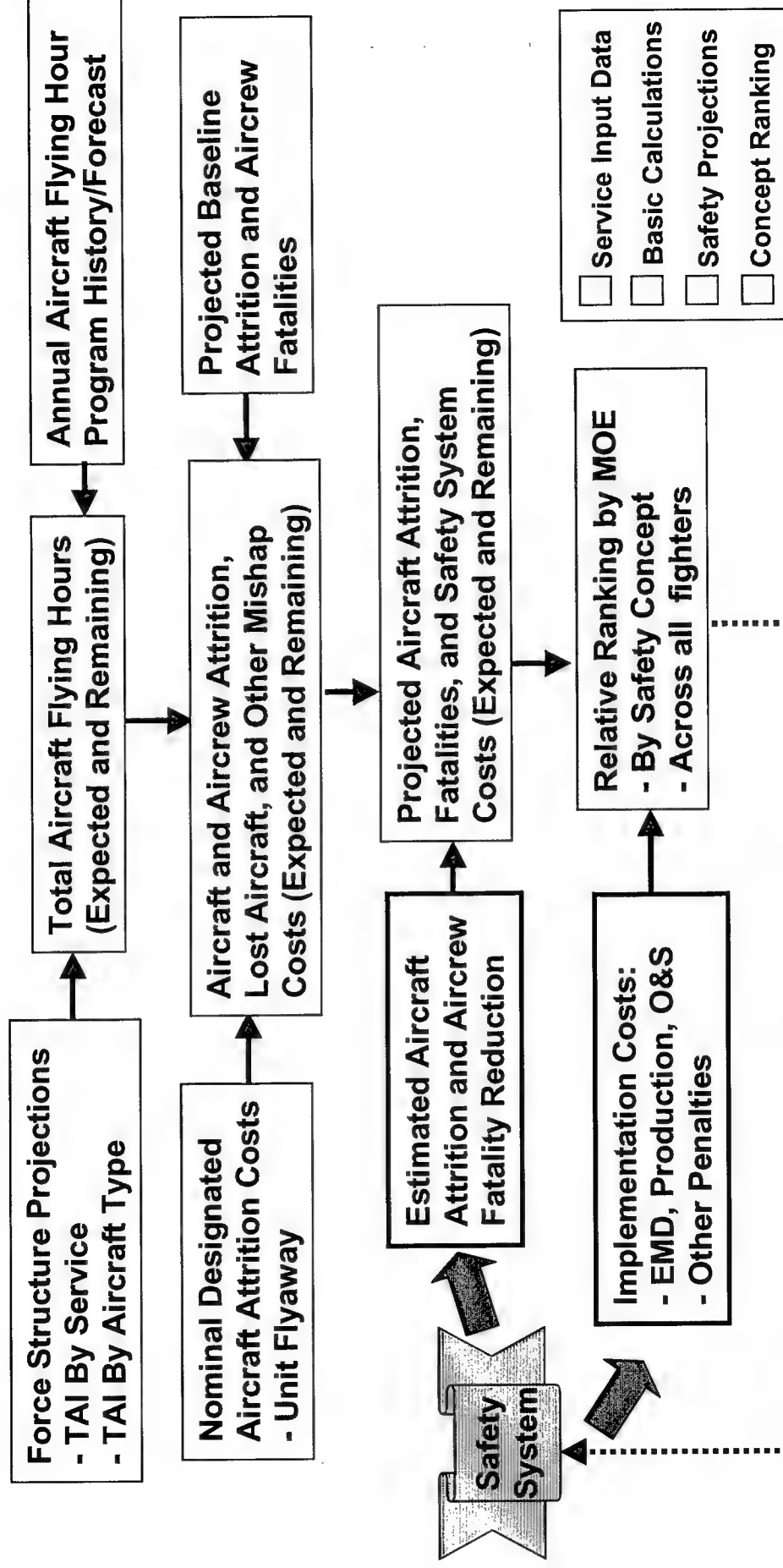
Using historical data and projections based on Service input, IDA calculated the expected mishap numbers and mishap rates for each aircraft. Given the projected flying hours per year, IDA then converted those figures into projected aircraft and aircrew attrition numbers associated with the various causal factors. In addition, using unit flyaway cost as the nominal value of an attrited aircraft, IDA calculated the value of aircraft lost as well as the total cost of a mishap, taking into account other expenses associated with a mishap.

Once the projected aircraft attrition, fatalities, and cost of mishaps remaining in the absence of any new safety initiatives were calculated, IDA could then postulate new systems and safety concepts to estimate the impact of these

on the baseline figures. At the same time, IDA was able to use past studies and information from the various aircraft program offices to provide initial estimates for the implementation costs of the various alternatives. These costs included EMD, production, and O&S. Other potential penalties, such as weight and drag resulting from a new installation, were looked at qualitatively.

IDA then calculated a net monetary benefit for each system by subtracting the cost of implementing a concept from the value of mishaps averted over the remaining life of each aircraft. All four measures of effectiveness (number of aircraft and aircrew saved, value of mishaps averted, and total net monetary benefit) were ranked (or ordered) according to which aircraft/safety concept combination had the largest impact on each of the measures. More than one MOE was provided since concepts that have a significant impact on the mishap rate and have the potential to save more lives than others might be deemed preferable even if they do not appear at the top of the net monetary benefit list.

Detailed Methodology



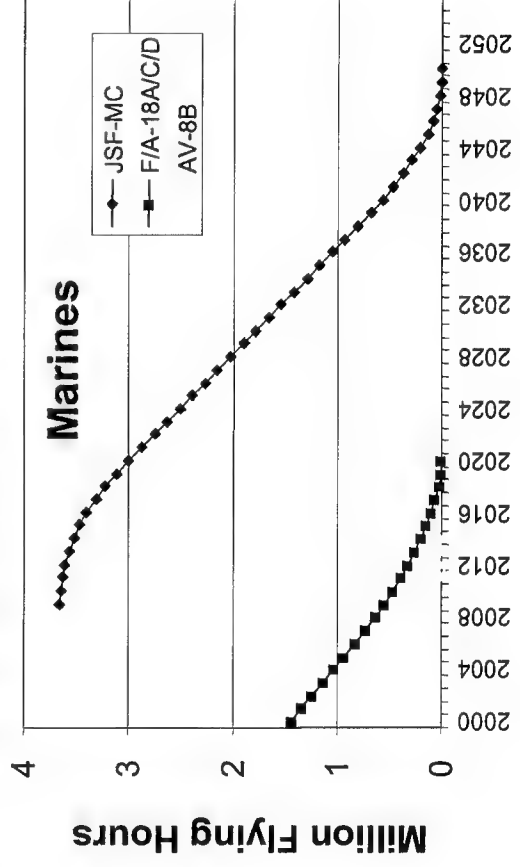
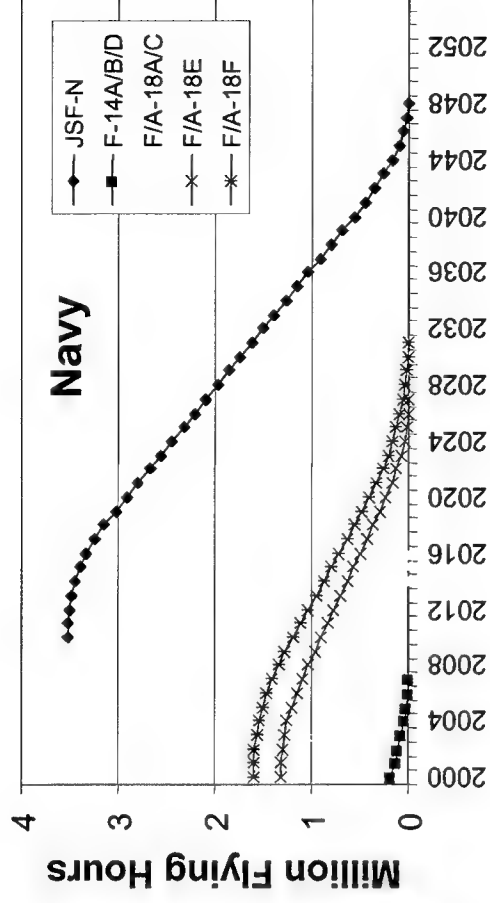
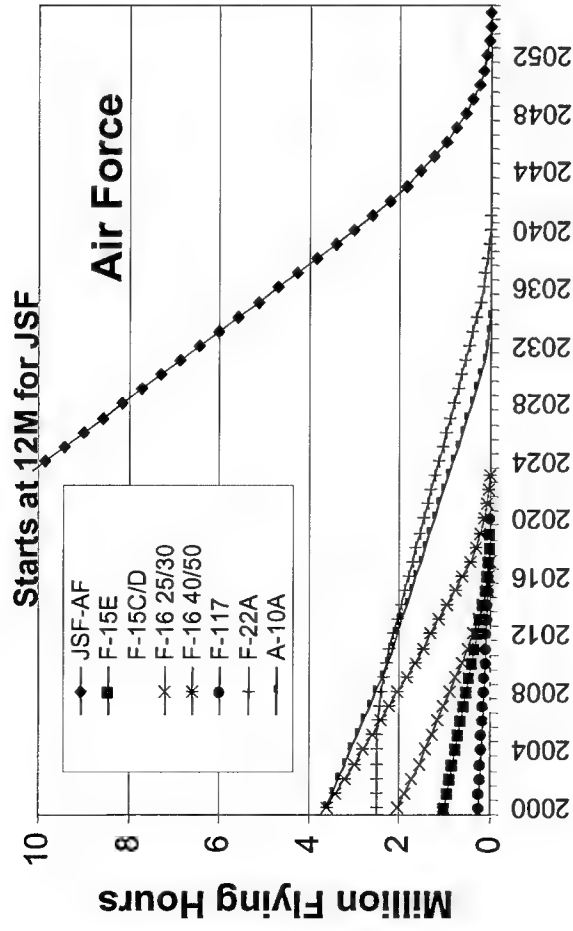
A major factor in determining the utility of a new safety concept is the remaining service life expected for each aircraft. The longer the remaining service life, the more opportunity a safety system, once installed, will have to avert mishaps and save aircraft and crews. Because of resource constraints, it may not be possible to implement all systems on all aircraft. Therefore, if all other costs and values are equal, the priority should go to the aircraft/system combinations with the potential for averting the largest number of mishaps. That potential is a function of the number of years and flying hours remaining for each aircraft. IDA measured the expected flying hours remaining by calculating the total number of flying hours by year based on historical trends and Service inputs. The inclusion of time in this factor is essential because it takes into account the fact that alternative safety systems may be introduced at different times (due to their current maturity) and over different time periods (due to the differences in aircraft fleet size).

The chart displays the projected number of flying hours remaining by year for the Air Force, Navy, and Marine Corps fighter aircraft considered in the study. These projections were based on the planned aircraft force structures provided by each Service, standard Service planning factors such as Air Force Instruction (AFI) 65-503, FY 2000 POM budget documents, and historical flying hour per aircraft experience.

Major changes in the future flying hour programs can significantly alter the resulting safety system MOEs. As an example, the recent decision to retain the A-10A in the Air Force inventory until 2030 moved systems associated with that aircraft much higher in the rankings because of the corresponding increase in projected flying hours and years that these safety systems could now impact.

For each Service the JSF dominates all other aircraft considered in terms of the flying hours remaining. This is not surprising since the system is expected to be the backbone of all three Service fighter fleets for the next 50 years. For the Air Force, the JSF fleet is predicted to generate a total of about 12 million flying hours. The two F-16 versions (Block 25/30 and 40/50 series) analyzed will each generate slightly less than 4 million hours of flying time over the next 20 years, while the A-10A will produce the same number of hours over a longer 30-year span. Once it is fielded, the F-22A is expected to fly over 2.5 million hours through the year 2040. For the Navy, the F/A-18E/F fleet has the second largest number of flying hours remaining after the JSF. The F-14 has the fewest hours and the shortest service life remaining. In the Marine Corps, the F/A-18A/C/D has the next largest number of flying hours remaining behind the JSF, drawing down as the JSF is introduced.

Projected Aircraft Flying Hours Remaining



This slide shows the aircraft projected to be lost in the future due to mishaps or aircraft attrition remaining (without any new safety systems) for the considered Air Force, Navy, and Marine Corps fighters. For current aircraft, the projected attrition is based on a detailed analysis of their respective Class-A mishaps to date, including number, rate, and cause. Over time, their cumulative lifetime Class-A mishap rates are expected to follow documented historical trends, which show mishap rates decreasing through time as the fleet matures. This rate of decrease will be much smaller as an aircraft approaches retirement. Given the Services' extensive experience with the current aircraft, IDA attributes a reasonably high confidence to these attrition rate estimates.

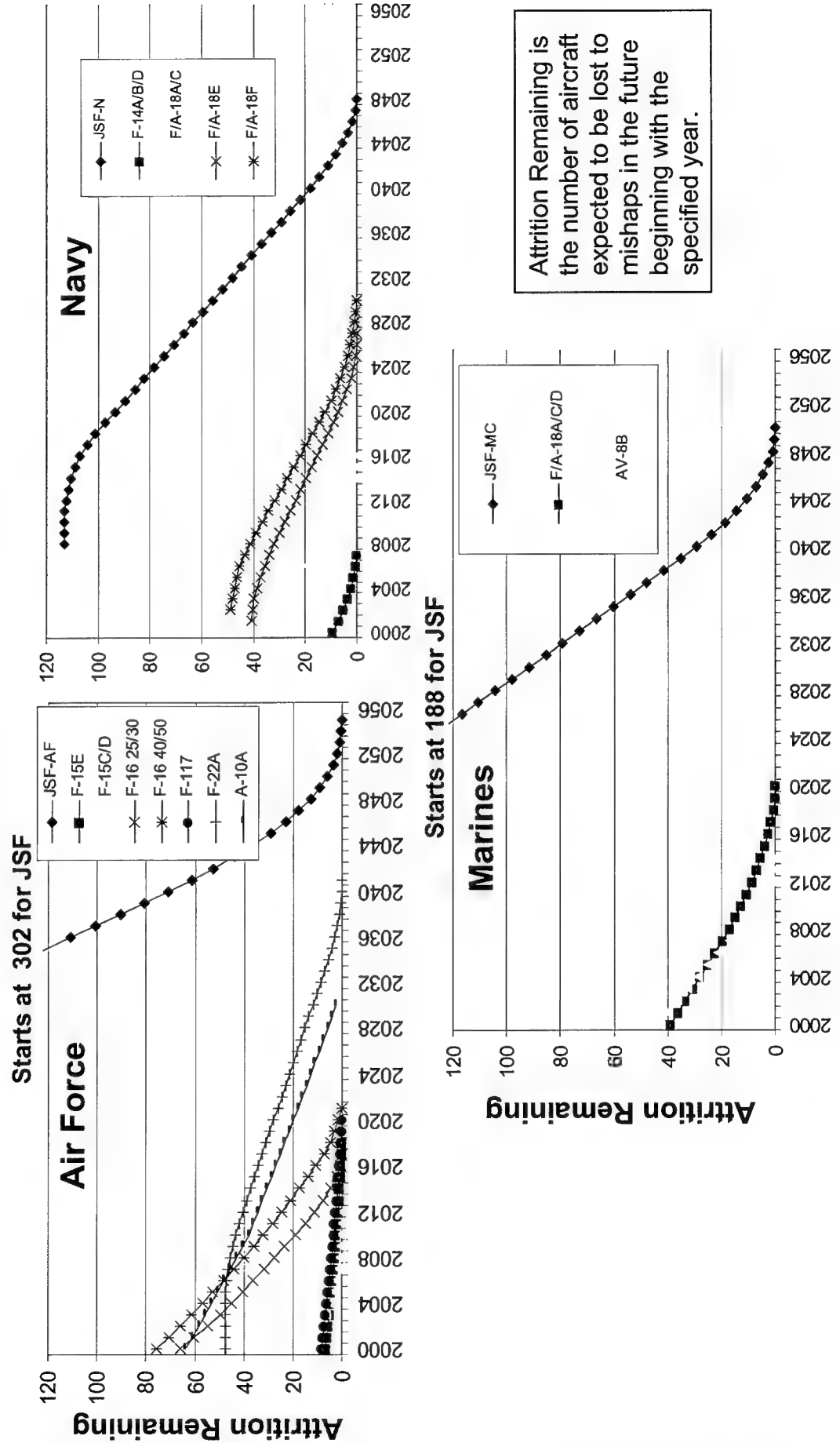
IDA has less confidence in the estimated attrition rates for the new aircraft because these systems are not yet fielded and there is uncertainty in their subsystem design, projected reliability, and overall use patterns. The expected attrition for the F-22A was taken from a recent IDA study focused exclusively on that aircraft.⁴ For the JSF and F/A-18E/F, judicious estimates were made using analogies to the historical trends of the other aircraft based on their mission, service, number of engines, initial operating capability (IOC) year, and takeoff/landing mode (conventional or vertical-capable). Appendix A provides additional information on specific attrition rates for the fighters addressed in the study.

⁴ *Costs and Benefits of the Installation of Certain Flight Safety Systems on the F-22A Aircraft*, IDA Paper P-3487, October 1999, UNCLASSIFIED. (See particularly Chapters III and VI.)

The projections shown here indicate that for each Service, the JSF dominates all other fighters in terms of projected attrition remaining. Because the JSF is expected to be the primary aircraft in terms of numbers and flying hours for all Services over the next 50 years, the fact that they are projected to suffer the greatest numerical attrition is not surprising. The Air Force, Navy, and Marine JSF attrition is predicted to be 302, 113, and 188 losses, respectively, over their projected half-century lifetimes. Other aircraft follow similar trends to those shown and discussed on the previous flying hours last chart.

This chart provides a basis for some initial general observations. First, if a safety system truly has benefit in reducing attrition, the earlier it can be implemented, the more aircraft it can save. The projection in 2000 is for 10 additional F-14 aircraft to be lost to mishaps over its remaining service life. If an all-encompassing safety system was available today but EMD and production cycles meant it could not be fully implemented until 2006, it would save only one aircraft. For proven systems, there is no advantage gained by delay. A related conclusion is that safety systems postulated for new aircraft will generally have a larger impact than those on existing aircraft of equal fleet size, largely because new aircraft will be around longer and have higher remaining attrition. This does not mean, however, that current systems should be overlooked just because there are fewer attrition aircraft to affect. That decision will depend on the specific safety benefit, the related costs, and the priority placed by the decision-maker on reducing mishaps.

Projected Aircraft Attrition Remaining (No New Safety Systems)



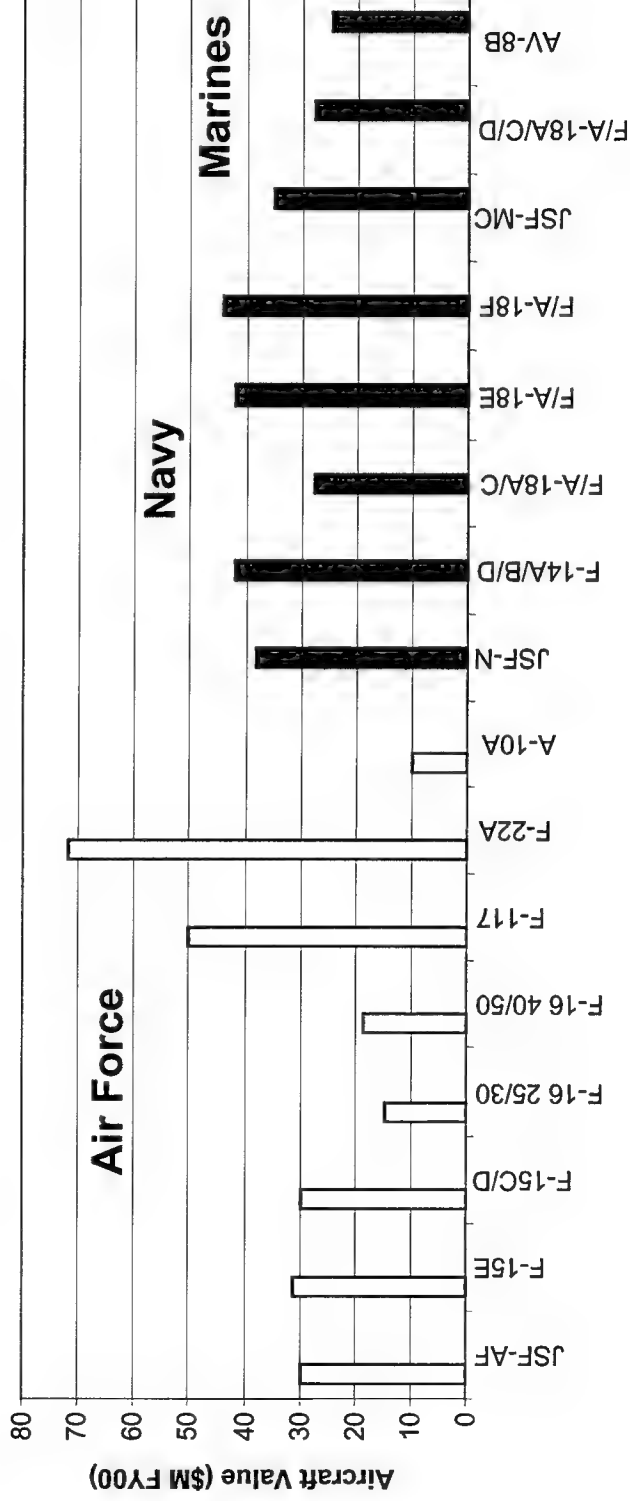
The fly-away cost of each aircraft considered by the study, grouped by Service, is illustrated in this chart. The costs are used to provide a benchmark value in millions of FY00 dollars for an aircraft saved from destruction by a new safety system. For the baseline, these values are not depreciated and are assumed to remain fixed throughout the service life of the aircraft. This assumption reflects the reality that the value of an aircraft rests in its availability for or capability in combat, the timing of which cannot be predicted over the course of an aircraft's service life. A classic example for this approach is the B-36 Peacemaker, which was never involved in combat even though during much of its 13-year service life it was the backbone of the U.S. strategic deterrent force. The standard economic argument would be that the value of the aircraft should be depreciated through time, so that an aircraft lost to mishap would have less value as it approached retirement. On the other hand, the operational perspective associates the value of a combat system with its availability to perform the mission. The value of the B-36 may actually have increased through time its deterrent contribution took on more importance in the face of the Soviet Union's development of credible nuclear forces not projected when the B-36 was fielded. An argument can even be made for increasing the value of aircraft through time based on the fact that the aircraft that replaced the Peacekeeper, although offering some increased capability, was double the B-36 cost.

Improvements added over time (like the Conventional Munitions Upgrade for the B-1B) would also increase aircraft value. Rather than debate the issue, and in the absence of other compelling value information, IDA used flyaway costs provided by the Services as a surrogate for aircraft value and did not change these values through time.

As an excursion, IDA did examine the impact of a simple straight-line depreciation case. For ease of calculation, the values provided by the Services were reduced linearly throughout the life of the aircraft, either from 2000 for current fighters or from the estimated full operational capability (FOC) date for the new fighters to a zero value at retirement date. Essentially, this accepts the position implied by the publication of a single value for each fighter type that all aircraft of that type, have the same current value, despite year of production. It then applies parallel logic to each new fighter type which are also assessed to be a uniform value at the aircraft's FOC date despite year of actual production. A more precise application of depreciation would calculate a different value for each aircraft tail number depending on year of production and then depreciate each aircraft through time (as well as use Monte Carlo techniques to postulate which aircraft are lost to future mishaps). This approach would involve a complexity and resource investment that exceeds the scope of this study without providing additional insight

Aircraft Monetary Values

- Undepreciated: same fixed value throughout service life
 - Sources: AFI65-503, Navy Safety Center, JSF JORD



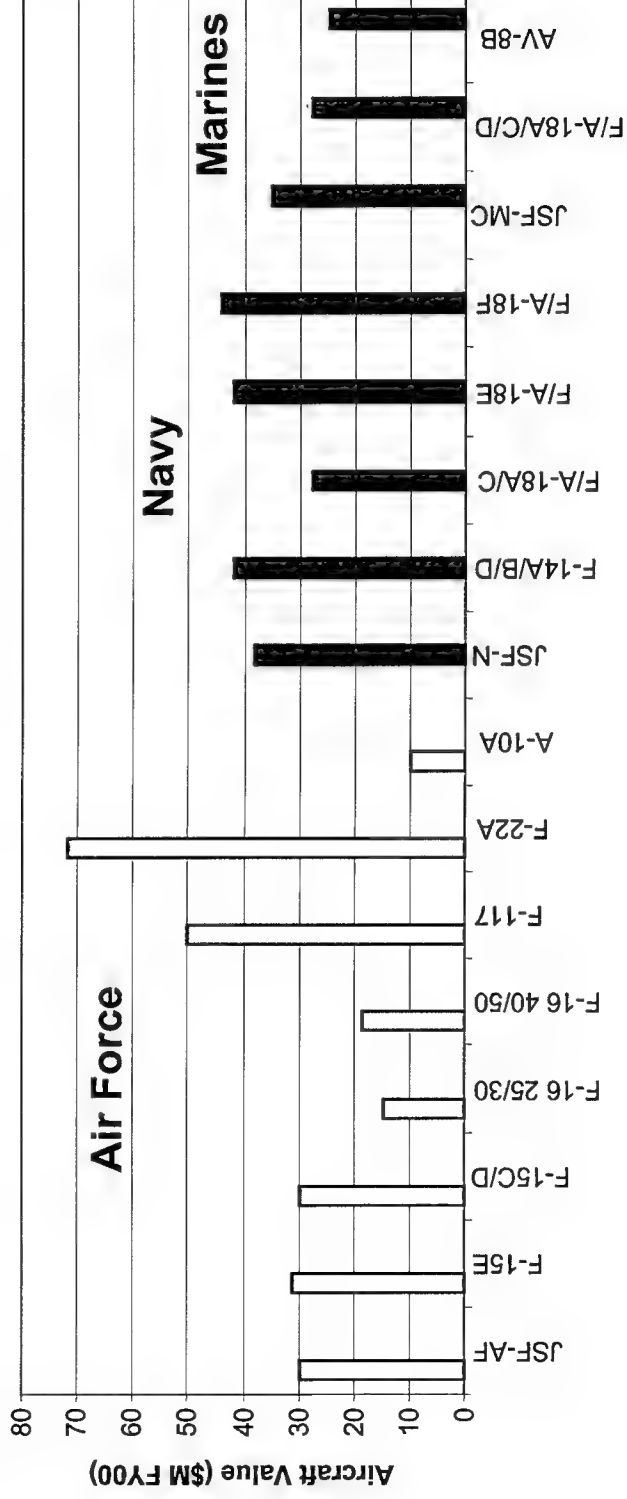
- Depreciated (not shown): value progressively reduced (from 2000 or full operational capability date) to zero at retirement date

on the primary excursion objective, which was to determine whether the relative rankings changed if aircraft value decreases over time. Instead, the technique used allowed the study team to treat current and future aircraft in the same manner while determining the sensitivity of results to depreciation. Specifically, it provides insight for the military operator or defense decision-maker who believes that an aircraft's value is "used up" over time. A chart is included in Appendix A that shows the depreciated values over time for the aircraft considered in the study. Analysis of the rank-orderings of the depreciated cases shows little change in the results from the non-depreciated cases. As expected, the absolute value of the total net benefit MOE for most systems is reduced, since this measure would then be calculated based on the depreciated value of mishaps avoided in the future minus concept application costs that are generally higher in the earlier years of system implementation. Although not investigated in this study, increasing value through time (e.g., if the value of a lost \$19 million F-16 were associated instead with the \$28 million price of the newest F-16 Block 60 production model or the \$30 million JSF projected to replace the F-16) would have the opposite impact on the net benefit MOE, increasing the monetary benefit associated with safety concepts.

Even if net flyaway cost is fully accepted as the appropriate value measure, the figures shown here are highly contentious, in both absolute and relative terms, as discussed by the General Accounting Office, the Congressional Budget Office, and others. Since the purpose of this study is not to resolve the value debate but rather to provide a rank ordering of safety system impacts, IDA used DoD documents such as AFI 65-503 for Air Force aircraft, the Navy Safety Center for Navy/Marine aircraft, and the JSF Joint Operational Requirements Document (JORD) for the three JSF variants for this source data. Where a single value is shown for multiple aircraft variants (such as for the F-14 A/B/D), the number represents the weighted average value.

Aircraft Monetary Values (Continued)

- Undepreciated: same fixed value throughout service life
- Sources: AFI65-503, Navy Safety Center, JSF JORD



- Depreciated (not shown): value progressively reduced (from 2000 or full operational capability date) to zero at retirement date

This slide shows the monetary value of the projected aircraft attrition remaining (without any new safety systems) by year for the Air Force fighters considered. The monetary value of the remaining Air Force aircraft attrition was determined by combining the expected attrition remaining with the monetary values of the aircraft as shown on the previous chart.

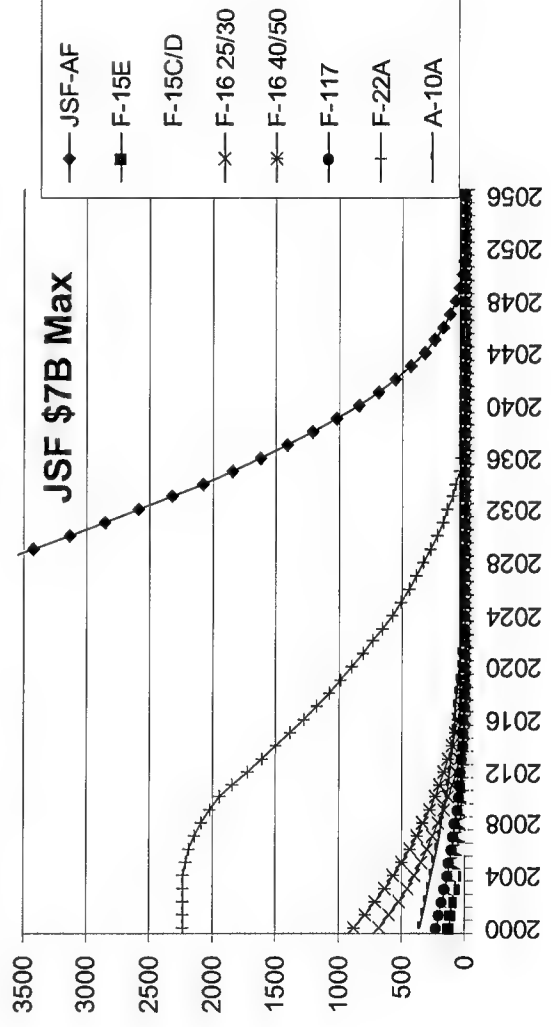
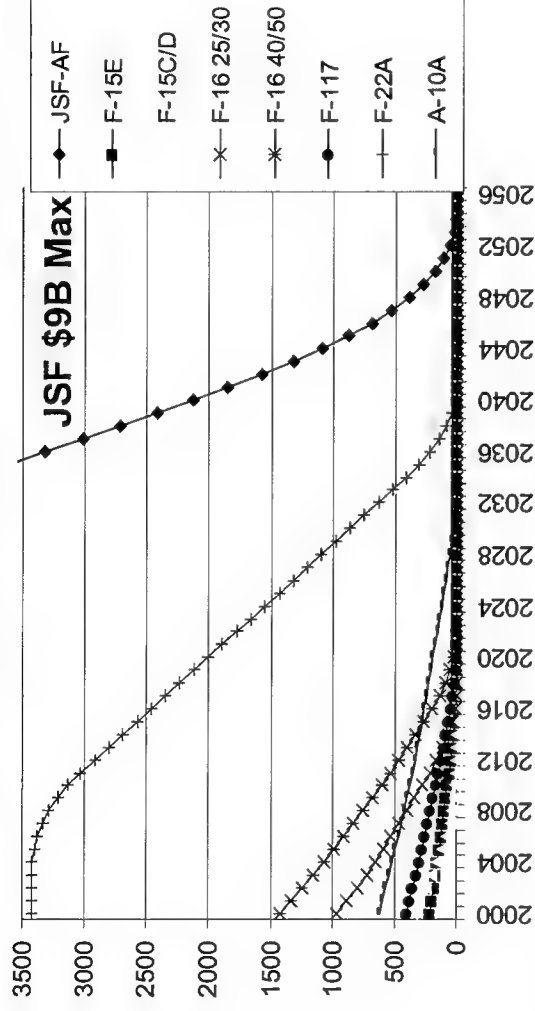
The slide displays both the baseline case without depreciation and the excursion case with depreciation. Using depreciated values suppresses the overall value associated with the remaining Air Force aircraft attrition. As an example, the maximum value of the remaining attrition of the Air Force JSF variant is reduced from roughly \$9 billion to about \$7 billion, a difference of \$2 billion or about 22 percent. The maximum monetary value of the remaining F-22A attrition is reduced by over 35 percent, from about \$3.5 billion to \$2.25 billion. In most cases, the aircraft retain their relative position with respect to other aircraft except that the crossover point between the A-10A and the Block 25/30 F-16s occurs earlier when comparing the undepreciated case to the depreciated one and later for A-10A and the Block 40/50 F-16s.

In both the baseline (without depreciation) and excursion (with depreciation) cases, the AF variant of the JSF represents by far the greatest monetary value of the remaining aircraft attrition over time. The F-22A produces the next highest monetary value of attrition for Air Force fighters.

The monetary value of the remaining aircraft attrition represents the absolute maximum amount of aircraft value saved that could be generated by the incorporation of a new safety system in a fighter. Because mishaps result from a variety of causes and safety systems are generally not able to address all causes, new safety concepts are expected to avert only some fraction of the total mishaps. As a result, only a corresponding fraction of the dollar value amount shown here would actually be averted from attrition by a specific safety system. In addition, since each system requires an implementation time that can vary between aircraft, the expected attrition value saved will be even lower.

Regardless of whether Service fly-away costs or other figures are used to establish attrition value, normal budget considerations suggest that the figures shown here represent a practical ceiling for safety system investment. For example, the chart suggests the maximum attrition associated with the F-15E fleet will be \$250 million. Safety systems whose implementation costs significantly exceed this figure should not be ranked highly, particularly since the time to implement and the expected fractional impact will ultimately result in significantly less attrition value averted than the \$250 million shown here.

Monetary Value of Projected AF Aircraft Attrition (\$M FY00)



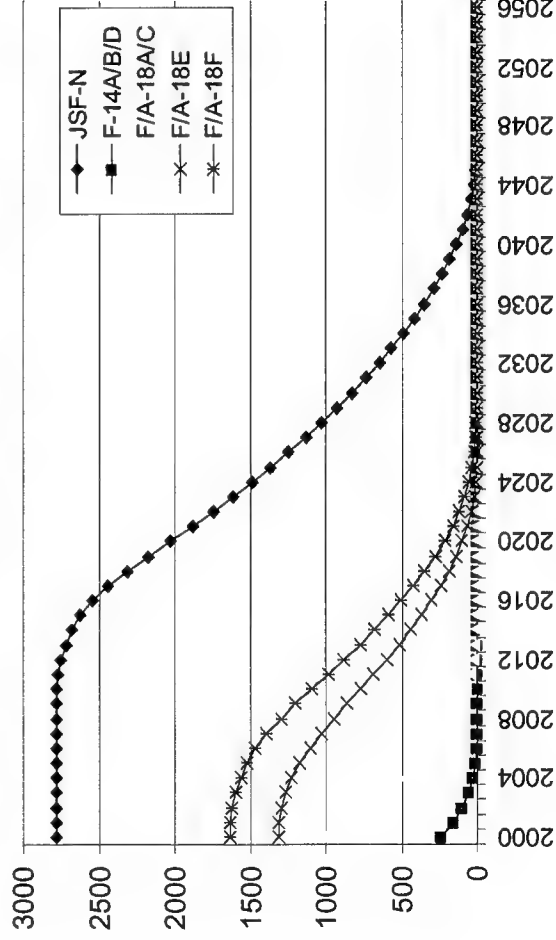
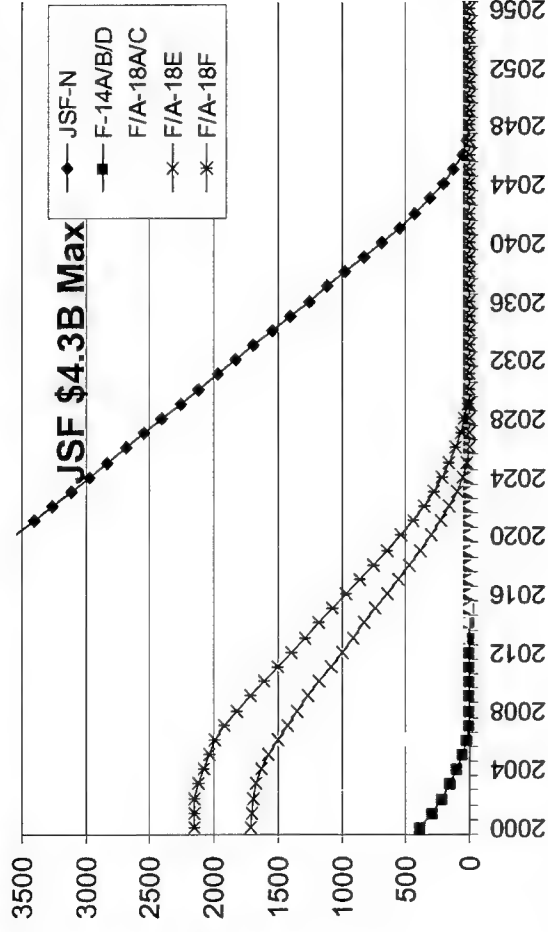
As in the Air Force case, this slide shows the monetary value of the projected aircraft attrition remaining without any new safety systems, by year, for the Navy fighters considered. This monetary value was determined using the same methodology as that described previously for the Air Force aircraft.

Both the baseline case without depreciation and the excursion with depreciation are again displayed. Depreciation greatly suppresses the overall value of the remaining Navy aircraft attrition. As an example, the maximum value of the remaining attrition for the Navy variant of the JSF is reduced from roughly \$4.3 billion to about \$2.8 billion, a difference of \$1.5 billion or 35 percent. The maximum monetary value of the remaining F/A-18E/F attrition is reduced about 24 percent, from a total of roughly \$3.8 billion to about \$2.9 billion.

In both the baseline (without depreciation) and excursion (with depreciation) cases, the Navy JSF represents the greatest monetary value of the remaining Navy aircraft attrition over time. Following the JSF in terms of monetary value of the remaining aircraft attrition is the F/A-18E/F.

As with the other Services, the monetary value of the Navy's remaining aircraft attrition represents an absolute maximum that can potentially be saved with the incorporation of new safety systems. Only some fraction of this amount would actually be saved by any individual safety system concept since specific safety systems are unlikely to be universally effective in eliminating all mishaps resulting from all causal factors. In addition, since the implementation time would be different for each aircraft/system combination, this will also decrease the amount of attrition value that can be impacted. The maximum value of undepreciated attrition averted for the combined F-14A/B/D (using the weighted average value of the A, B and D models) is just over \$400 million in the current year ramping down to less than \$200 million by 2004.

Monetary Value of Projected Navy Aircraft Attrition (\$M FY00)



This slide follows the format of the previous two charts to provide an estimate of the monetary value of the projected aircraft attrition remaining (without any new safety systems) by year for the Marine Corps fighters considered. The monetary value of the remaining Marine Corps aircraft attrition was determined using the same methodology as previously described, combining the value of each aircraft with the expected attrition remaining.

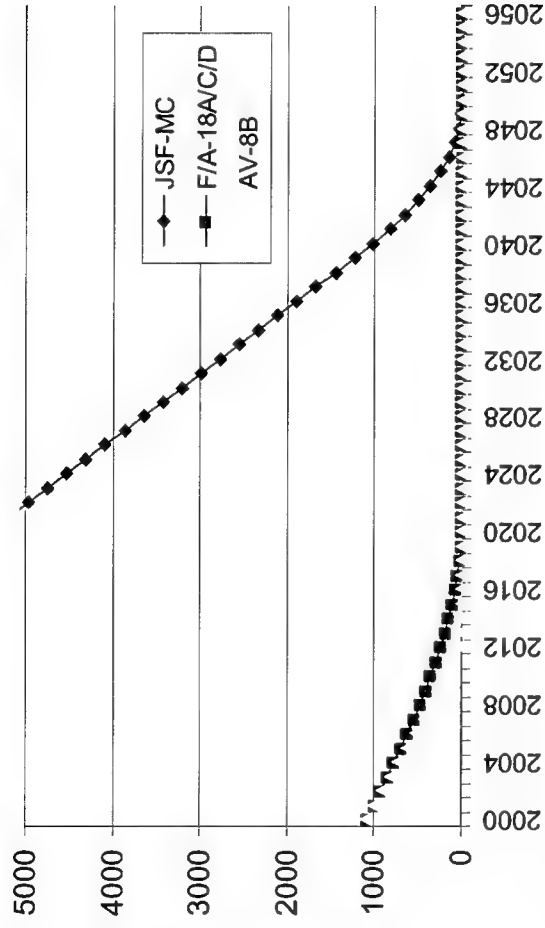
Both the baseline case without depreciation and the excursion with depreciation are displayed. As with the earlier estimates, using depreciated values greatly suppresses the overall value of the remaining attrition. As an example, the maximum value of the remaining Marine Corps JSF variant attrition is reduced from roughly \$6.7 billion to about \$4.8 billion, a difference of \$1.9 billion or about 28 percent. The maximum monetary value of the remaining F/A-18A/C/D and AV-8B attrition combined is reduced over 36 percent, from about \$2.2 billion to \$1.4 billion. In both the baseline (without depreciation) and excursion (with depreciation) cases, the JSF represents by far the greatest monetary value of the

remaining Marine Corps aircraft attrition over time. The other aircraft are out of the inventory by the early to mid-2010s. While this is only slightly after the retirement of the Navy's F-14 aircraft, because of the numbers involved and the projected attrition rates, the value associated with the Marine Corps F/A-18s and AV-8s is such that a safety system on the Marine aircraft could potentially avert twice the attrition as the same system with the same effect on the F-14.

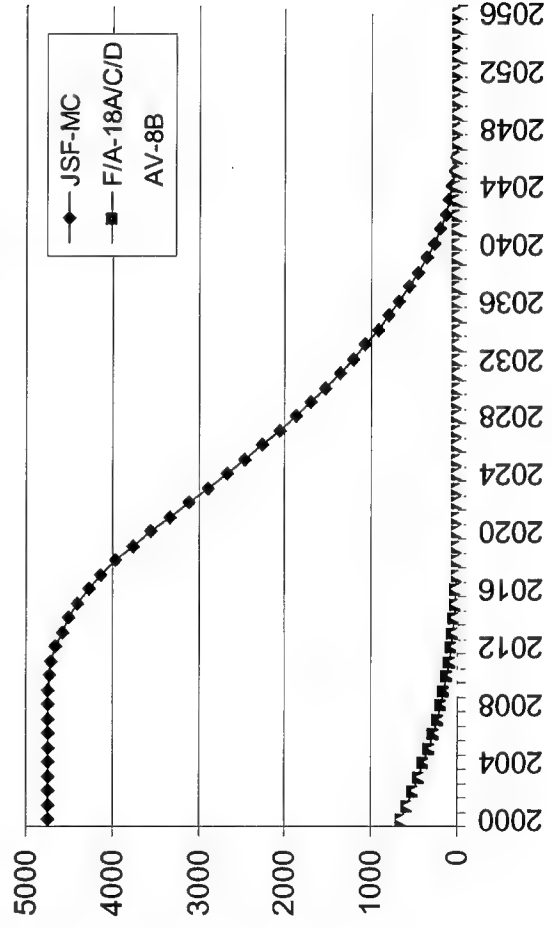
As noted on the other Service aircraft slides, the monetary value of the remaining aircraft attrition represents the absolute maximum potentially savable by new safety systems. Only some fraction of this amount would be expected to be saved with a specific safety system concept. In addition, the implementation time would be different for each aircraft, which also would reduce the amount of attrition value that could be saved by any specific concept.

Monetary Value of Projected USMC Aircraft Attrition (\$M FY00)

Undepreciated
Case



Depreciated
Case



In the course of this study, IDA conducted a comprehensive review of the available historical Class-A mishap data pertaining to current Air Force, Navy, and Marine Corps fighter aircraft. IDA focused on Class-A mishaps for several reasons. First, Class-A mishaps nearly always represent aircraft destruction or attrition for fighters (approximately 95 percent of the time for the F-15 and F-16, as shown in Appendix A), as well as pose a significant risk of aircrew fatality. Reducing Class-A mishaps has the greatest potential for saving lives and protecting combat capability. In addition, because they have a high profile, Class-A mishaps are accorded the greatest attention by senior DoD and Service leadership as well as by other elements of government. In addition, anecdotal evidence suggests that systems designed to improve Class-A mishaps can also have a corresponding beneficial effect on the other classes of mishap. Finally, the effort needed to conduct the same level of investigation into the other mishap categories would have greatly exceeded the resources available for the study.

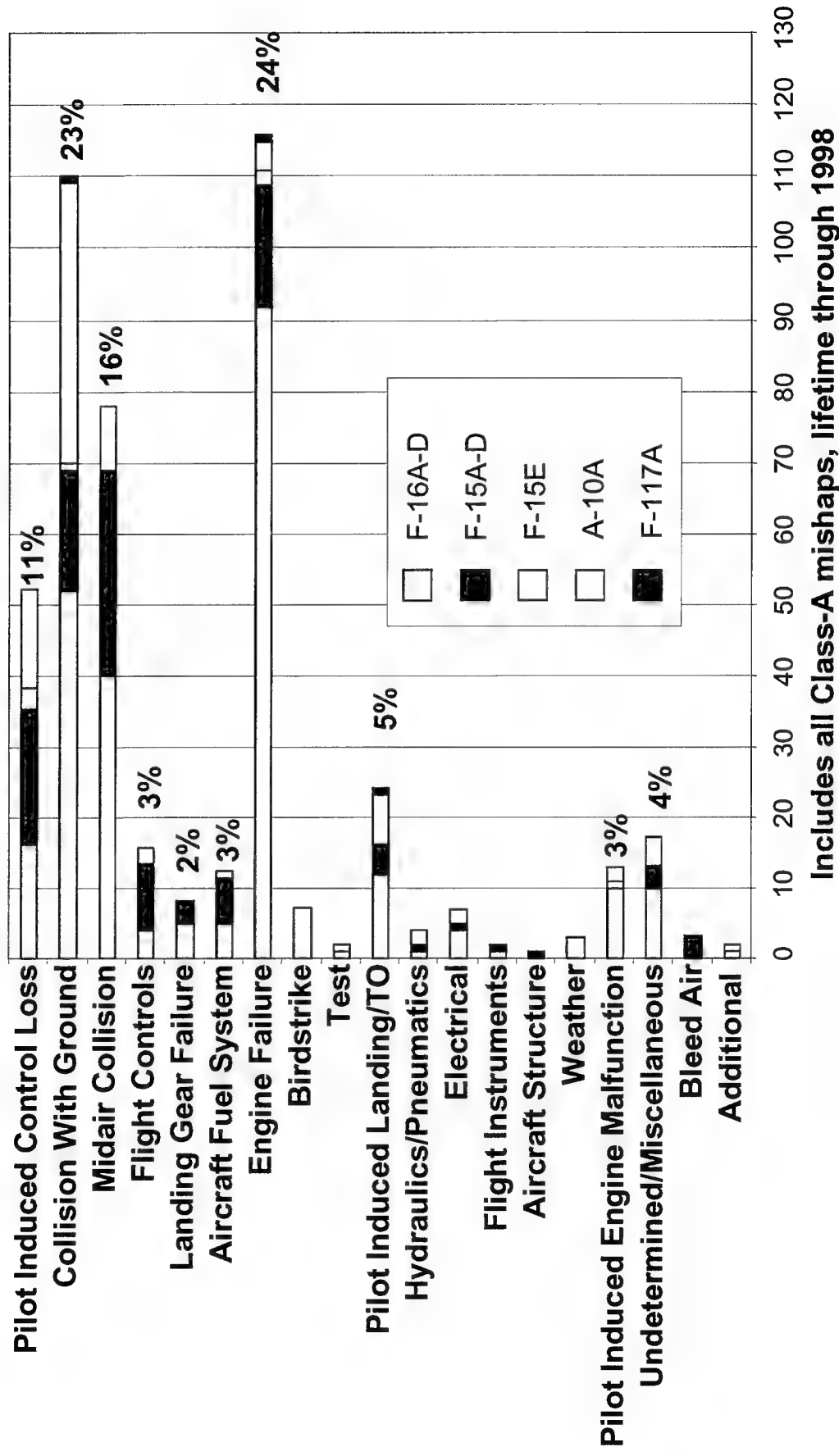
The chart on the facing page displays the number and distribution of all Air Force Class-A mishaps by cause for the five current fighters considered by this study. The data includes all Class-A mishaps over the lifetime of these fighters (through FY98) and uses the Air Force Safety Center's taxonomy for assessing primary cause. The contribution each of the five fighter types made to each cause area is also displayed. The top 10 overall causes are identified by the percent number appearing to the right of each bar. The highest contributor to Class-A mishaps has

been Engine Failure, accounting for 24 percent of all accidents by these five fighters, most of which are associated with the F-16. Additional contributors to major mishaps are Collision with Ground (primarily by the F-16 and A-10) at 23 percent, Midair Collisions (primarily by the F-16 and F-15A-D) at 16 percent, and Pilot Induced Control Loss (associated primarily with the F-16, F-15A-D, and A-10) at 11 percent. The remaining 6 of the top 10 causes each contributed 5 percent or less of the total mishaps. The F-15E and F-117 are hardly visible in the chart due to their comparatively small number of mishaps.

The chart suggests that if a new concept could eliminate engine failure in the F-16, the overall fighter mishap rate would be dramatically reduced. By the same token, a concept aimed at resolving hydraulic or pneumatic problems, even if it could be applied to all aircraft, would generate no more than a 1 percent drop in the number of Air Force fighter Class-A mishaps.

Those reviewing the data for the first time might be surprised by the percentage of pilot induced control losses. The statistics shown here include not only those instances where a pilot might have unintentionally flown an otherwise fully functional aircraft into an aerodynamic regime from which recovery was not possible (such as a stall or spin), but also those instances where an aircraft emergency or other event or mission tasking created channelized attention, leading to the same end result. In either case, the chart suggests that training approaches or systems that help the pilot recognize the approach to these regimes in order to avoid them could have a beneficial impact.

Air Force Fighter Class-A Mishap Distribution by Cause



This chart displays the same data shown in the previous chart but broken out by mishap cause for each fighter aircraft rather than by fighter aircraft contributions to each mishap cause. The figures provide the number and distribution of all lifetime Class-A mishaps through FY98 for each current fighter considered in the study. The causal factor breakout uses the taxonomy provided by the Air Force Safety Center. For reference, the overall lifetime Class-A mishap rate (mishaps per 100,000 flight hours) through FY98 is also provided in boxes under each aircraft label.

Due to their large number and high mishap rate, the F-16 constitutes over 50 percent of the Air Force fighter Class-A mishaps examined. Within the F-16's Class-A mishaps, Engine Failure, Midair Collision, Collision with the Ground, and Pilot Induced Control Loss were the largest causal contributors. These four causes alone constituted approximately 75 percent of the lifetime F-16 Class-A mishaps.

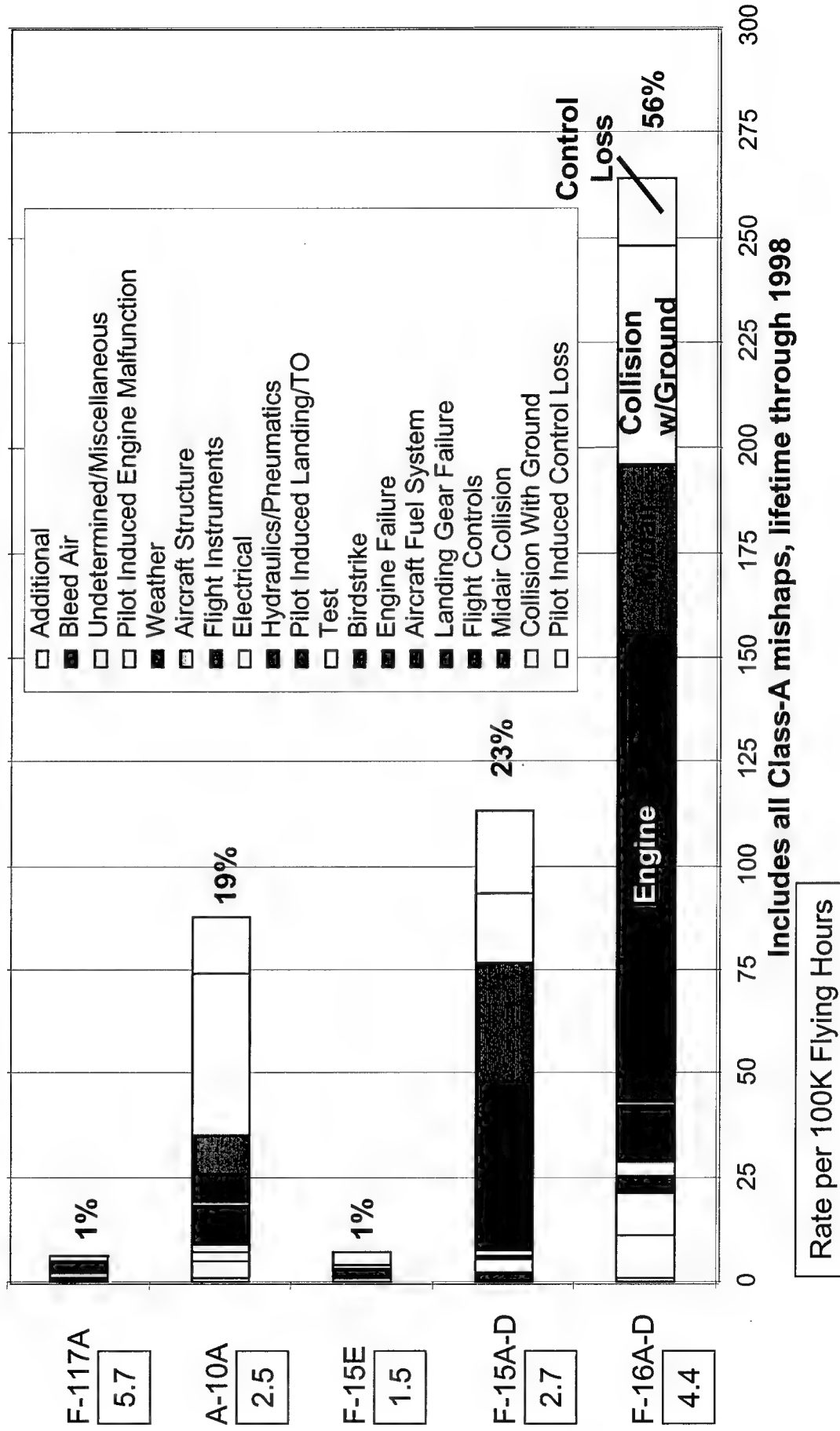
The F-15A-D and A-10A generated the next highest number of Air Force fighter lifetime Class-A mishaps examined, at 23 percent and 19 percent, respectively. With their two-engine configurations, the fraction of their Class-A mishaps due to Engine Failure is

significantly lower than the single-engine F-16. The dominant cause for major A-10A mishaps was Collision with the Ground, while the largest causal factor for the F-15A-D was Midair Collision.

Compared to the other Air Force aircraft, the F-117A and F-15E have had relatively few Class-A mishaps. Of the Air Force aircraft examined, the F-117A has had the largest lifetime Class-A mishap rate, at 5.7. As the data shows, however, even if all reasons for F-117A mishaps could be addressed and the mishap rate reduced to zero, such action would have a much smaller impact on the overall Air Force fighter mishap rate than just partially solving one of the F-16 cause factors.

The Navy mishap taxonomy differs from that used by the Air Force Safety Center and, because of the percentage of aircraft lost at sea and not recovered, fully detailed causal data for all mishaps are not available. To the extent possible, the IDA team used the same approach shown in the past two slides to analyze Navy and Marine Corps Class-A mishap data by aircraft and cause in order to forecast future mishap rates and the impact of potential safety concepts. Slides addressing Navy and Marine Corps mishaps are included in Appendix A.

Air Force Fighter Class-A Mishap Distribution by Aircraft



Because the engine failure category was the highest contributor to the fighter Class-A mishaps, IDA initiated a more in-depth assessment of the related engine failure data. The chart on the facing page shows a detailed mishap-cause breakout for the seven engines currently being used by the F-15/F-16 fleets, which were responsible for 95 percent of the engine mishaps involving Air Force fighters over the 10-year period ending in FY98.

In general terms, the failures were either maintenance induced (MI) or attributed to material failures of the various engine components themselves. The complexity of the modern jet engine, with its various turbine speed, temperature, and pressure combinations, can induce a multitude of failure modes. In every case where the IDA team identified more than two material failures associated with a specific component of one of the engines over the 10-year period, the Air Force had already identified the trend and completed an engineering design change to fix the problem. The only anomaly for which IDA could not confirm specific action concerned the high number of maintenance-induced failures across a range of components for the F110-100 engine (5 components contributed 14 maintenance-induced mishaps over the

10-year period). During the time period of the study, IDA was unable to confirm if a design change or maintenance training program had been developed to reduce maintenance errors.

The Services in general and the Air Force in particular devote significant resources to engine enhancements on an annual basis. While it is not always possible to determine how much of this investment is allocated to performance improvement and how much to mishap prevention, it was clear from this investigation that engine mishap trends are immediately identified and corrective engine design changes quickly developed. These design changes are normally incorporated during major engine overhaul cycles, although such changes have occasionally been accelerated or decelerated depending on a risk assessment provided by the involved program managers and Service leaders.

Since engine mishaps themselves are the result of a wide range of causes in the components of different engine/aircraft combinations, IDA was not able to identify specific areas outside the potential maintenance practices associated with the F110-110 where a new concept would have a significant impact on the engine-related fighter mishap rate.

F-15/F-16 Engine Related Mishaps (1989-1998)

Cause/Engine Type	F100-100	F100-200	F100-220	F100-220E	F100-229	F110-100	F110-129	Total	
Augmentor-MI			1			3		4	8%
Combuster					1			1	
Bearing		1	1			2		4	10%
Bearing-MI			1				1	2	
Bleed Air		1						1	
Controller	1	2		1				4	19%
Controller-MI		2	1			2		5	
External-MI		2						2	
Fan						1		1	
Fan Stage 1	1					1	4	6	
Fan Stage 1-MI						1		1	
Fan Stage 1-2		2						2	32%
Fan Stage 2-MI			1					1	
Fan Stage 3	1	2				1		4	
HPC		1				1		2	
HPC-MI						3		3	
HPT-MI						5		5	21%
LPT Stage 3/4				6				6	
LPT Stage 4	1	1						2	
Other-MI		2			1			3	
Unknown		1				1	1	3	10%
Total-MI	0	6	4	0	1	14	1	26	
Total All Causes	4	16	6	7	2	21	6	62	
MI-Maintenance Induced									
		HP-High Pressure	LP-Low Pressure	C-Compressor	T-Turbine				

No clear high-payoff investment areas, although maintenance training and procedures for the F110-100 should be reviewed

In addition to engine enhancements, IDA looked at approximately 40 different potential safety system technologies and human factor options for improving Class-A mishap performance of fighter aircraft. These concepts included those identified by the 1997 Defense Science Board study, as well as concepts derived from meetings with the sponsor, Service safety and operational experts, NASA study efforts, and other aviation safety literature. From this review, four safety systems concepts were selected for in-depth evaluation in this study. The screening criteria included factors discussed earlier in this report, such as the expected impact of a system or concept on the mishap rate, as well as technological feasibility (concepts needed to have at least a defined and technically understandable engineering approach to a solution, even if such an approach has not yet been fully implemented on any test aircraft) and data availability. The four concepts, Automatic Ground Collision Avoidance System (AGCAS), Midair Collision Avoidance System (MCAS), Emergency Parafoil Recovery System (EPRS), and Pilot Activated Automatic Recovery System (PAARS) are briefly summarized in this chart with a picture and a few descriptive bullets. Additional information on each of the concepts is available on the more detailed charts provided in Appendix A.

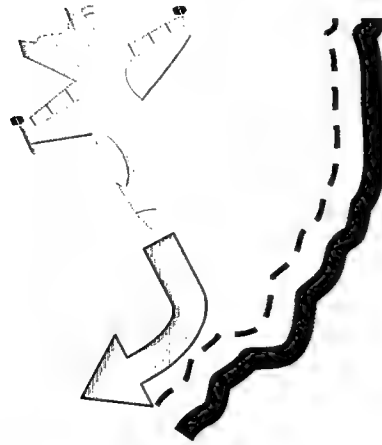
The AGCAS system envisions a software change to the aircraft's avionics and flight control systems to automatically take action to avoid hitting the ground. Using available position awareness systems [inertial

navigation, Global Positioning System (GPS), radar altimeter, etc.] and a digitized three-dimensional map of the ground over which the aircraft is flying, the system first provides an aural/visual warning and then activates the aircraft autopilot to automatically initiate a fly-up maneuver upon determination of impending aircraft impact with the ground or water (or some preset height above). It has been flight tested on the F-16 AFTI and a specially modified F-16D. It is planned for the Swedish Gripen and is presently a threshold requirement for the JSF (all versions). Optimization studies have minimized the false alarm rate and features are available to allow the pilot to override or turn the system off if desired for combat operations.

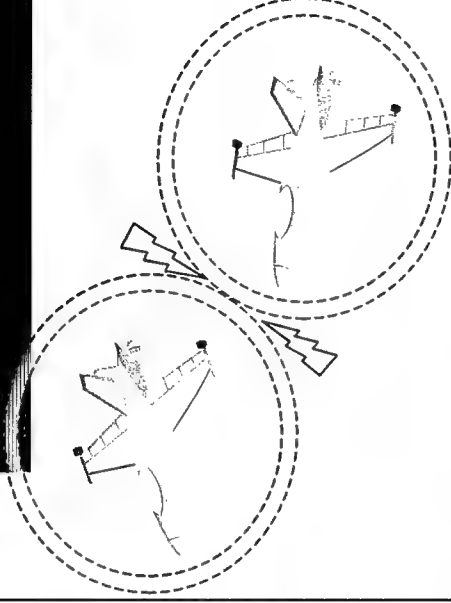
The conceptual MCAS system involves an aural/visual warning then automatic breakaway upon determination of impending impact with another aircraft in non-formation flight. For this study, the system is assumed to use a data link such as the F-22's Intra Flight Data Link (IFDL) or upgraded Joint Tactical Information Distribution System (JTIDS) to address similar type aircraft only, which historically have accounted for two-thirds of all Class-A mishap midair collisions. Such an initiative is part of the Naval Air Warfare Center (NAWC) ANGEL program and is an Air Force Research Laboratory (AFRL) initiative for FY00. Although the calculations in this study assumed the data link-based solution, other more comprehensive sensors/systems are possible for the long term.

Concepts Selected for In-Depth Evaluation

Automatic Ground Collision Avoidance System (AGCAS)

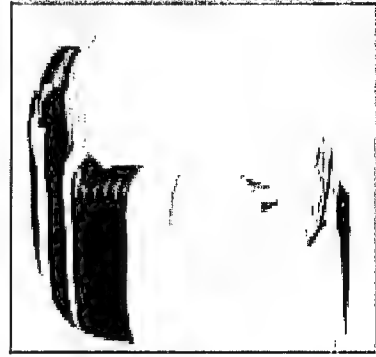


- Flight tested on AFTI and F-16D
- Planned for Swedish Gripen
- JSF threshold requirement



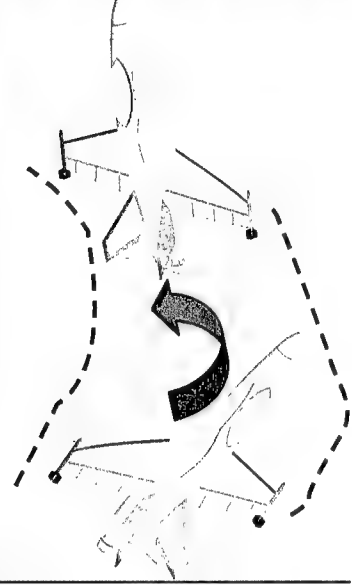
- Conceptual system part of NAWC ANGEL program, AFRL initiative
- Near term F-22 Intra Flt Data Link/JTIDS; long term, other sensor systems

Emergency Parafoil Recovery System (EPRS)



- Removable for combat
- Analogous system planned for NASA X-38
- Implementation issues include cost, weight and drag, operator resistance

Pilot Activated Automatic Recovery System (PAARS)



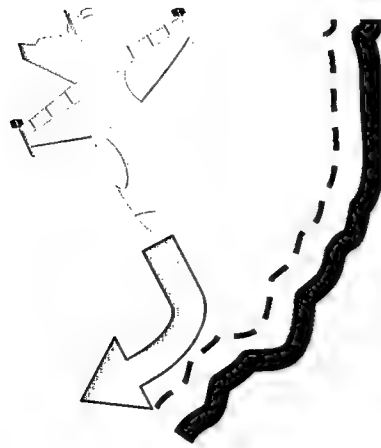
- Reduces mishaps resulting from spatial disorientation
- Installed on F-117 in early 1990s
- Optional additional feature with AGCAS

The EPRS system involves the manual or automatic deployment of a parafoil for a controlled, softer impact when an aircraft is unrecoverable (such as with the loss of the engine on a single-engine aircraft). Analogous systems have been postulated and demonstrated since the 1930s. Recently a 7,500 square foot (deployed) parafoil planned for the NASA X-38 Crew Return Vehicle (CRV) was successfully tested with an 18,000-pound load. Eventually, the parafoil will be installed on a 25,000-pound space test vehicle before finally marrying up with the X-38. The concept is for the X-38 to use the parafoil to fly autonomously to a flared touchdown using a GPS satellite-based guidance system. Current versions of the Block 60 F-16 have conformal fuel tanks along the top of the aircraft where the wings meet the fuselage. The size of these conformal tanks would be more than sufficient to handle the size and weight associated with a parafoil system. Depending on design, such a system could be removed for combat and replaced with fuel tanks to provide greater range in a war scenario. While a number of issues would need to be resolved for this system, it was the only concept that offered the potential to recover aircraft that suffer engine loss or some other catastrophic failure and are otherwise destroyed after aircrew bailout.

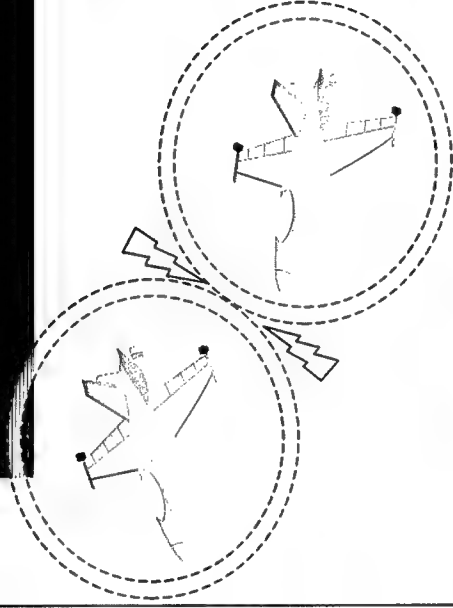
The final concept addressed in more depth by the study was PAARS, a system that automatically recovers an aircraft to stable attitude (wings level with slight climb) upon pilot activation. It was installed on the F-117 in the early 1990s. Although IDA was unable to locate data regarding how often it has actually been activated to assist a disoriented F-117 pilot, anecdotal evidence suggests pilot support for and appreciation of the system's capabilities. It could also be an optional add-on to AGCAS. A more advanced concept that includes a throttle adjustment mechanism could make the system even more useful in helping pilots escape unusual attitudes or pilot-induced loss of control situations.

Concepts Selected for In-Depth Evaluation (Continued)

Automatic Ground Collision Avoidance System (AGCAS)

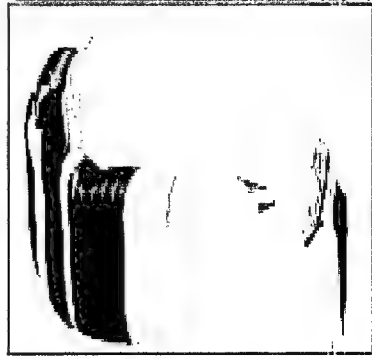


- Flight tested on AFTI and F-16D
- Planned for Swedish Gripen
- JSF threshold requirement



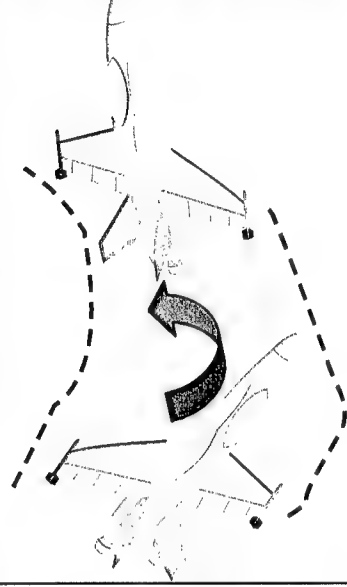
- Conceptual system part of NAWC ANGEL program, AFRL initiative
- Near term F-22 Intra Flt Data Link/JTIDS; long term, other sensor systems

Emergency Parafoil Recovery System (EPRS)



- Removable for combat
- Analogous system planned for NASA X-38
- Implementation issues include cost, weight and drag, operator resistance

Pilot Activated Automatic Recovery System (PAARS)



- Reduces mishaps resulting from spatial disorientation
- Installed on F-117 in early 1990s
- Optional additional feature with AGCAS

Having selected the four safety concepts, the IDA study team then produced separate cost estimates for each concept implemented on each fighter addressed by the study. The basic starting point for these estimates was the detailed cost profile developed by IDA for an AGCAS system on the F-22 aircraft.⁵ A key assumption was that implementation for each system on each type of aircraft (e.g., F-16 vice F/A-18 vice F-22) was a stand-alone project. This means that cost estimates developed here do not take into account any synergies associated with a staggered implementation plan across aircraft where lessons learned from one fighter type are passed on to another. The study did postulate EMD and production savings associated with the implementation of each safety concept with all three versions of the JSF combined, as well as for the Navy's F/A-18E and F models combined and for the separate Navy and Marine Corps F/A-18A/C/D combined since the effected systems within each of these groups of fighters are almost identical.

The A-10A was taken to be the most expensive airframe for implementing the flight control related concepts (AGCAS, MCAS, and PAARS). While exact costs will require a full engineering study to determine whether the current flight controls can be augmented or whether a new flight control system will be required, IDA assumed a worse case and used costs based on those associated with the original F-16A flight control system to serve as a basis for estimating a new A-10 flight control

⁵ *Costs and Benefits of the Installation of Certain Flight Safety Systems on the F-22A Aircraft*, IDA Paper P-3487, October 1999, UNCLASSIFIED. (See particularly Chapter IV.)

system capable of supporting any or all of these three safety technologies.

Reviewing the F-22 cost profile, IDA determined that the costs for a PAAR system would be less than the AGCAS system because PAARS does not require an active interface with the flight control system. On the other hand, MCAS is likely to be more complex than AGCAS so IDA used higher estimated costs to reflect this. EPRS EMD and individual production costs were estimated to be the same across aircraft types but significantly higher than AGCAS since EPRS requires more than just the computer hardware and software changes associated with the other systems. For EPRS, aircraft skin had to be opened, parafoil attachment systems incorporated, parafoils installed and, in some cases, new drag coefficients and weight and balance profiles established. These modifications require significantly greater resources than for the other alternatives.

The analyses included developing both a production schedule and a fielding schedule. The production schedules can be grouped into two types. The first covers aircraft currently in production or future aircraft. For these, production and fielding follow the current planned schedules. The second case addresses the situation where aircraft are already produced and fielded. In this situation IDA assumed that a retrofit program would be implemented with the production planned for completion in a nominal 3-6 year time frame, depending on the number of systems required.

Cost Estimation Methodology for Safety Concepts

- **Using IDA's F-22 Safety System Study as a baseline, study team applied appropriate models and analogs to develop reasonable cost estimates for each concept's**
 - **EMD**
 - **Production**
 - **Operations and Support**
- **Costs estimated for each relevant aircraft type, potential dates of system introduction, and annual funding flows**

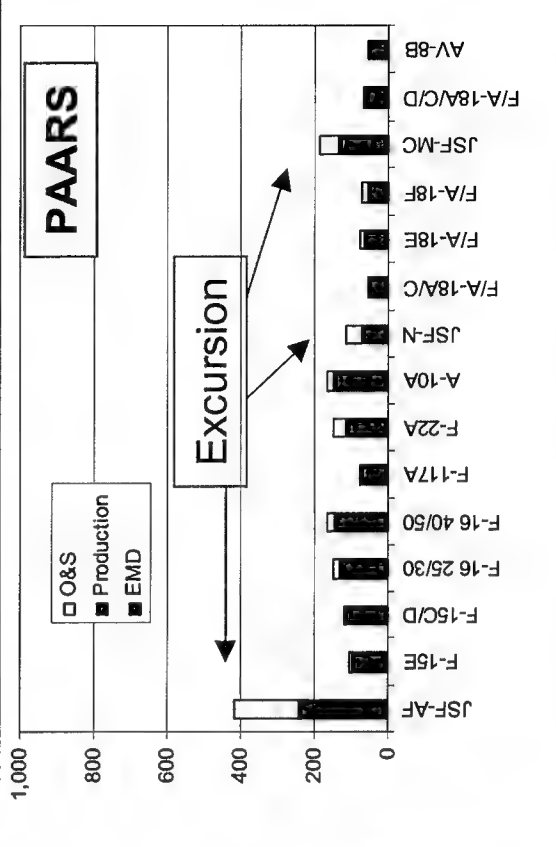
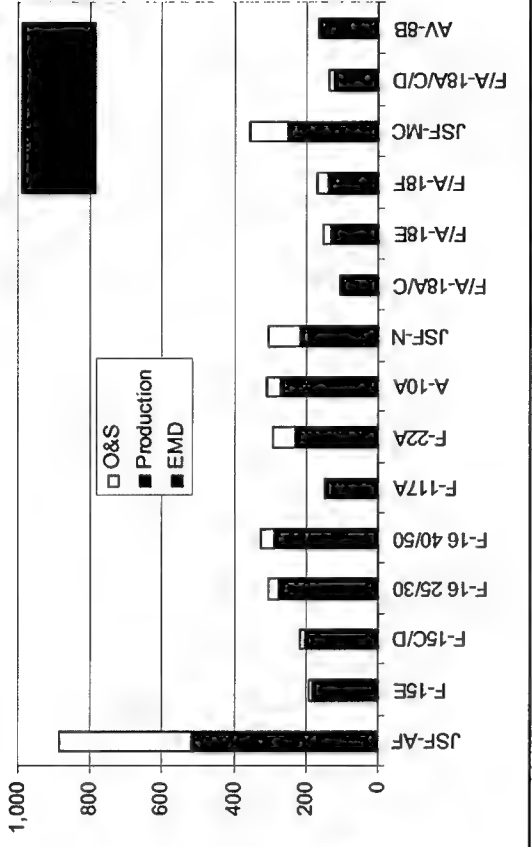
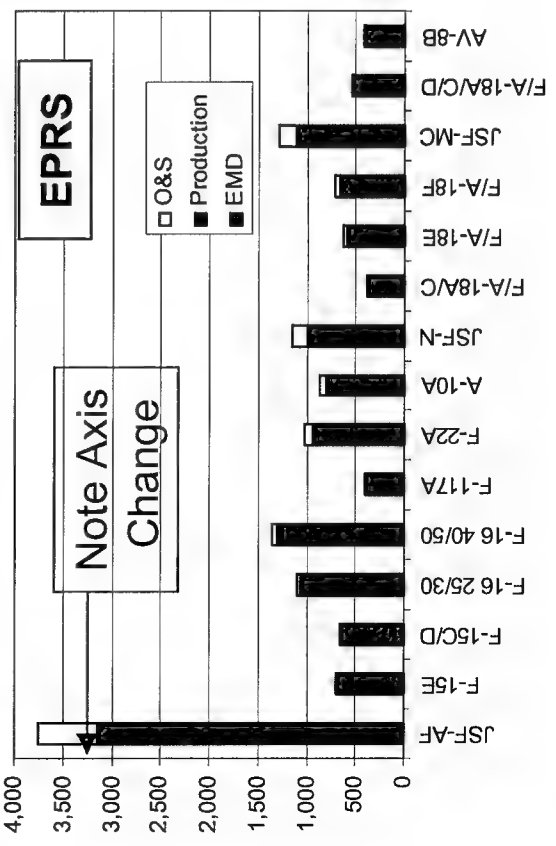
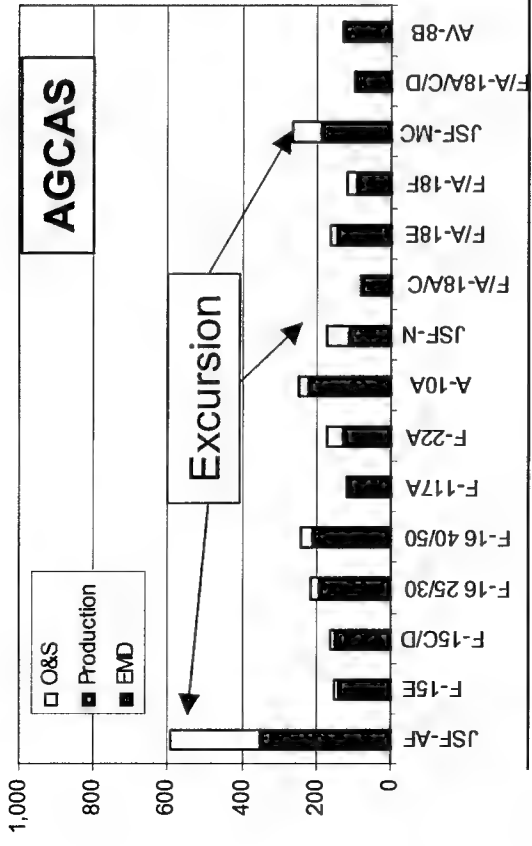
This chart presents the estimated costs for developing, producing, installing, and operating the four systems. The bars show for each aircraft type the sum of the EMD, production, and O&S costs. A detailed description of each follows.

The cost estimates for the AGCAS, MCAS, and PAARS were based on detailed AGCAS costs developed for the F-22A. EMD costs for F-22 AGCAS were estimated to be \$65 million in FY00 dollars. Without detailed engineering estimates available for other aircraft, IDA assumed that EMD for AGCAS on other aircraft would require additional engineering and therefore increased the costs derived from the F-22 by just over 50 percent to \$105 million for each aircraft type, except for the JSF combined, F/A-18 models, and the A-10. For the JSF the team started by totaling EMD costs as if each model was developed as an individual aircraft. This sum of \$315 million was then reduced to \$225 million to account for the similarity of the three configurations. Since the F/A-18E and F models have identical control configurations, the team used \$105 million to cover EMD for both aircraft. For the F/A-18A/C/D, the EMD cost of \$105 million was split equally between the Navy and Marine Corps versions. For the A-10, because of its non-automated flight control system and the potential need to redo the entire system to provide interface for AGCAS, the team estimated the EMD cost for that aircraft to be \$125 million.

MCAS EMD costs were increased relative to AGCAS to account for the fact that the MCAS system requires a real-time input from an outside source (another aircraft) as well as the fact that the MCAS system must calculate and predict over a three-dimensional space and provide unique maneuver inputs depending on an aircraft's relation to another fighter to avoid possible collision. For MCAS EMD the team used a nominal \$125 million cost for most aircraft types. The team used the same assumptions discussed previously for the JSF, F/A-18E/F, F/A-18A/C/D, and A-10. These resulted in an MCAS EMD for the JSF of \$285 million and \$150 million for the A-10. The F-18 costs were divided as discussed previously.

For PAARS EMD costs the team used a nominal \$75 million for most aircraft types, using the same approach as discussed earlier to address the JSF combined, F/A-18s, and A-10. This results in an EMD cost of \$175 million for the JSF and \$85 million for the A-10. The costs are assumed to be lower than for AGCAS since it does not have to sense collision with the ground or water (or with another aircraft). Such a pilot-activated system would not require the interfaces and continuous flight control commands associated with AGCAS and MCAS.

Safety Concept Implementation Cost Estimates (\$M FY00)



For the EPRS system EMD, the team used a nominal \$250 million for most aircraft types. The same assumptions as previously described were used for the JSF and F-18 variants. These resulted in a \$575 million EMD cost for EPRS on the JSF and a \$125 million EMD cost attributed to any individual F-18 variant (E/F or Navy/Marine version of the F-18A/C/D). The costs were higher than the AGCAS because EPRS has not been developed or tested on any tactical fighter aircraft. The system is being tested on the X-38, but IDA was unable to obtain cost estimates from that program. Because of the tests that will be required, the estimate shown here is more uncertain than for the others and may be low.

Production costs were based on the AGCAS first unit cost and learning curve slope. The F-22 generated a first unit cost of \$300,000 with a slope of 93 percent. All aircraft types used these same values except for the A-10 where the first unit cost was increased to \$1,500,000 to cover the costs of a new flight control system and/or adding electronic equipment to the existing mechanical flight control system. For the three JSF configurations the production costs were based on all the units being built on a single production line. Similarly the F/A-18E and F/A-18F production costs are based on a single production line. This assumption was also applied to the Navy F/A-18A/C and the Marine Corps F/A-18A/C/D. Note that production costs are also driven by the number of aircraft that must be equipped. For example, the 3 JSF models total 2863 aircraft as compared to some current fighters that number less than 100.

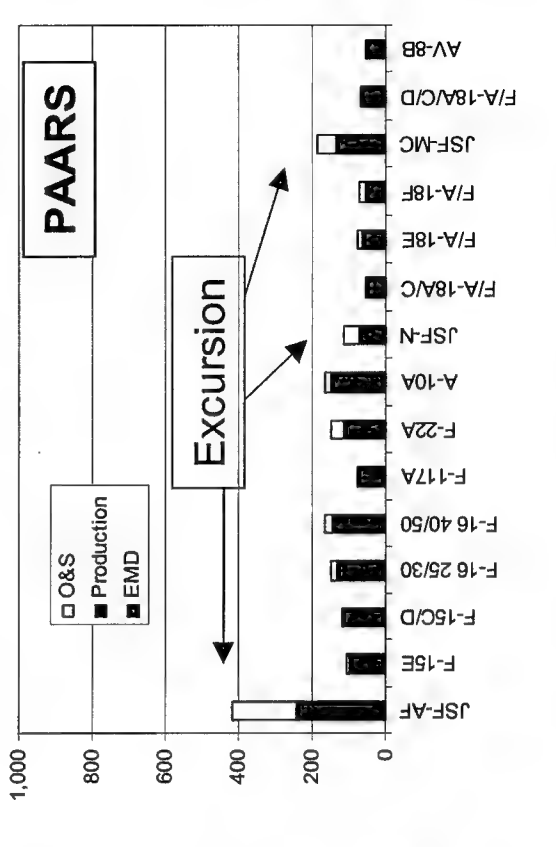
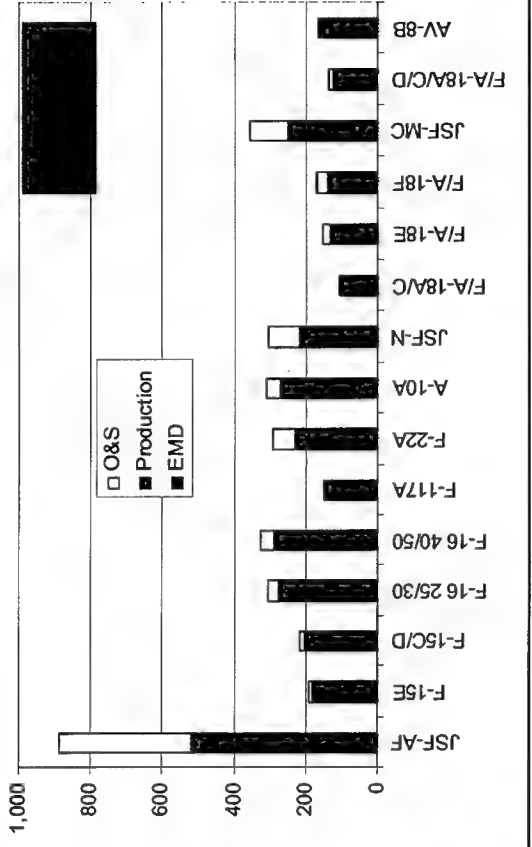
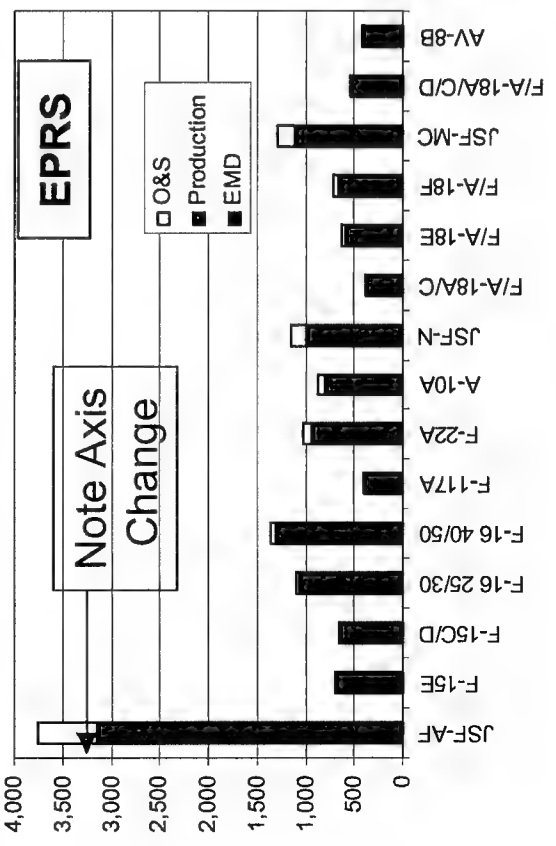
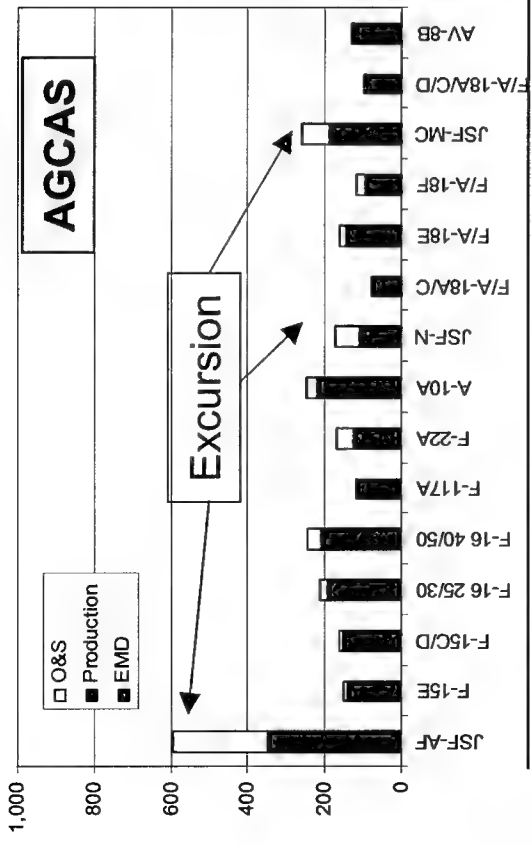
For MCAS production costs, the team increased the first unit cost to \$500,000 to cover the additional capability required of the MCAS system. All aircraft types used this value except for the A-10 whose first unit cost of \$1,750,000 covered adding electronic equipment and/or replacing the mechanical flight control system. As with AGCAS, production costs for certain aircraft were based on all units being built on a single production line.

For PAARS, the team decreased production cost of the first unit cost to \$200,000 because of the decreased capability required of this system. All aircraft types used this value except for the A-10 whose first unit cost was \$1,300,000 to cover adding electronic equipment to or replacing the mechanical flight control system. As with the AGCAS and MCAS, JSF and F-18 variants were assumed to be built on a single production line.

First unit cost for the EPRS system was estimated to be \$3,500,000 to cover the container, installation, airframe strengthening, parafoil, and separate guidance control system. The standard single production line assumptions used earlier were applied to the JSF and F/A-18 variants as previously discussed.

Safety Concept Implementation Cost Estimates

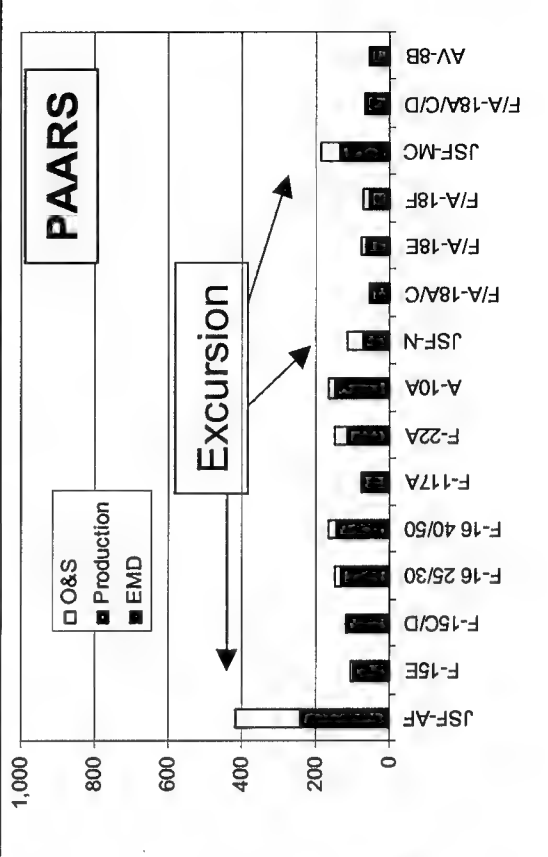
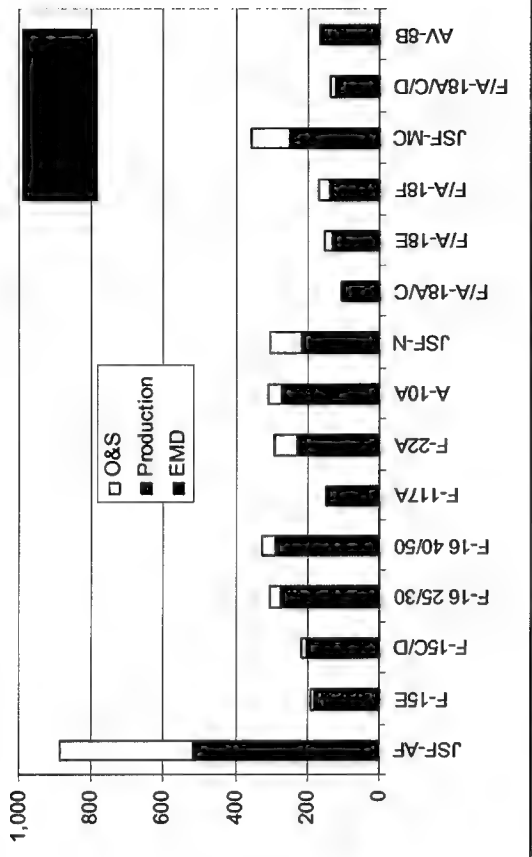
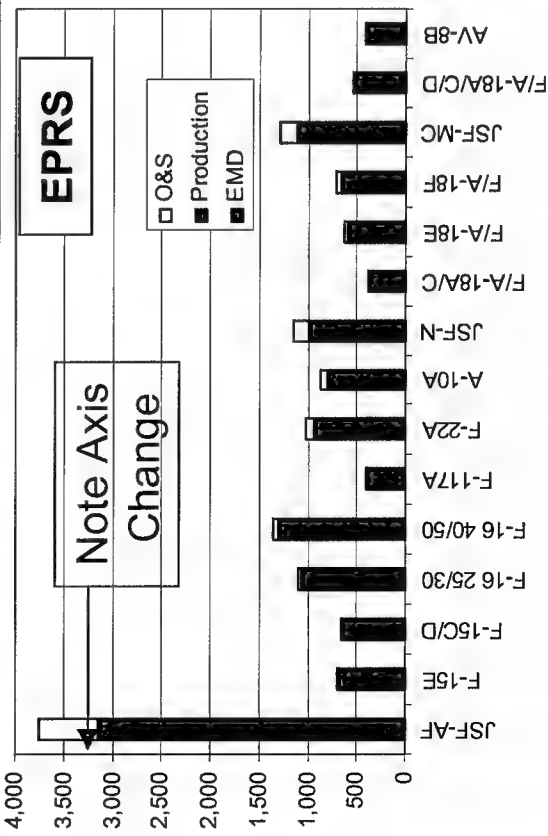
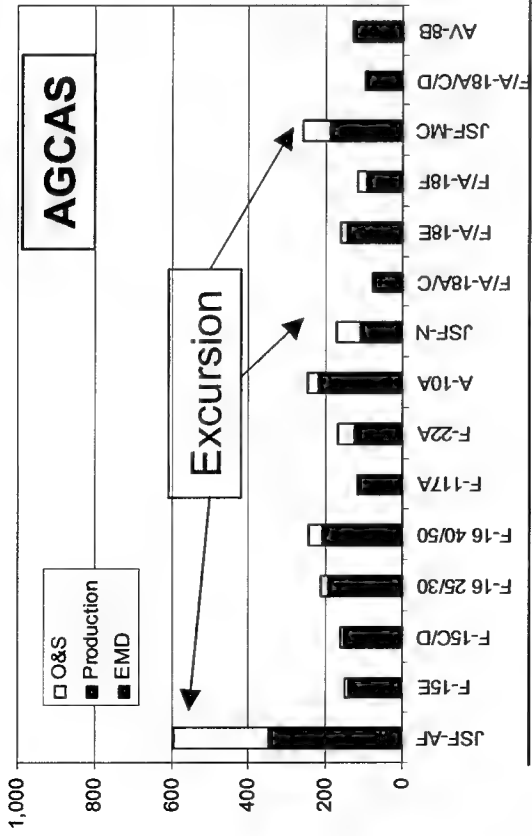
(\$M FY00, continued)



Estimates for O&S costs were based on the \$5,000 per aircraft per year AGCAS O&S costs for the F-22. This cost includes software maintenance and sustaining engineering at the depot. The cost was multiplied by the number of aircraft in the fleet each year that type of aircraft is in service to generate the total O&S cost. The per aircraft per year cost developed for the MCAS system was \$7,500, an increase over AGCAS to account for the increased complexity of MCAS. PAARS O&S costs were lower than those of AGCAS, reflecting the reduced number of interfaces and controllers associated with that system. The resultant cost per aircraft per year for PAARS was \$3,500. EPRS system O&S costs were \$12,500 per aircraft per year, partly to account for a small number of parafoils being tested each year and partly because recurring checks and replacements would generate higher costs than would be associated with an aircraft's internal computer hardware and software systems. Each of these costs was multiplied by the number of aircraft in the fleet for each type and each system for each year of service to arrive at total O&S for the various aircraft/safety system combinations.

Safety Concept Implementation Cost Estimates

(\$M FY00, continued)



In order to assist with cost estimation and determine the impact of each concept over time, IDA also developed a schedule for implementing each concept on the fighters and then estimated when the potential mitigating effects of the concepts would be felt in the field. This chart presents implementation schedules for the Air Force aircraft included in the study. In each case IDA determined the start date for EMD initiation for each system/aircraft combination based on the maturity of the technology and the associated research and development completed to date. A nominal 3-year EMD program was assumed for each alternative. Fielding was based on initiating production the year following completion of EMD. Production and installation capability was assumed to mirror the experience of other similar systems previously installed on the same fighter aircraft. The length of fielding time is a function of the number of safety systems produced on an annual basis and the ability of the logistics system to install these safety devices during normal aircraft upgrade activity.⁶ Schedules for the new F-22 and JSF are based on installing systems on the production line, not on having to create a separate production and installation line for the proposed safety concepts. For aircraft already in the inventory, the

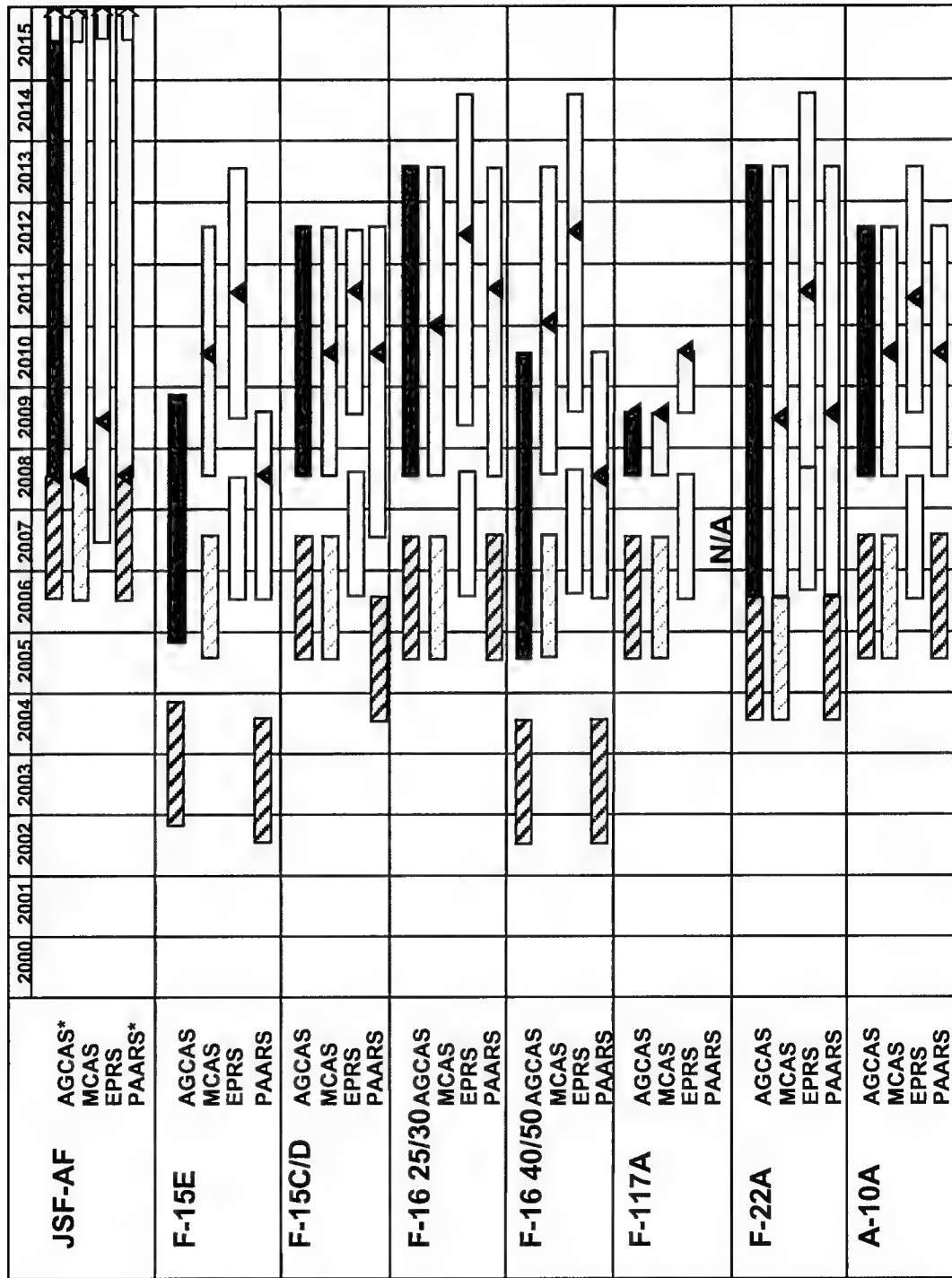
⁶ A separate upgrade activity (specifically to install the selected safety system) would potentially accelerate the fielding schedule, but was deemed too costly in terms of aircraft availability and overall program budget, as well as uncharacteristic of historical practices.

production schedule was designed to allow completion in a 3-6 year period depending on the size of each aircraft fleet.

The Automatic Ground Collision Avoidance System and the Pilot Activated Aircraft Recovery System, the two technologies for which most research and development is already complete, are judged to be available for installation earlier than the other alternatives. Within current aircraft, A-10 development is later than the others since its lack of a modern flight control system could require a new flight control system or additional integrating subsystems before the three concepts associated with flight controls (all but EPRS) can enter EMD.

As a final note, rather than ramp mishap mitigation benefits from zero just prior to safety system implementation to full implementation on the date of last aircraft modification, the study used the implementation midpoint (or the date the first aircraft leaves the production line for the JSF and F-22) as the "safety benefit determination year" to calculate the benefits associated with that system. Mathematically the two results are the same and the use of the midpoint simplifies the calculation as well as clarifies the time required for a safety concept to have an impact on the mishap rate. AGCAS on the F-16 is the earliest concept that can be fielded by the Air Force; normal time lines suggest that the earliest that concept could reach the field is 2005 for the Block 40/50 F-16s, with half that fleet modified by 2007.

Potential Safety Concept Implementation Schedule: USAF

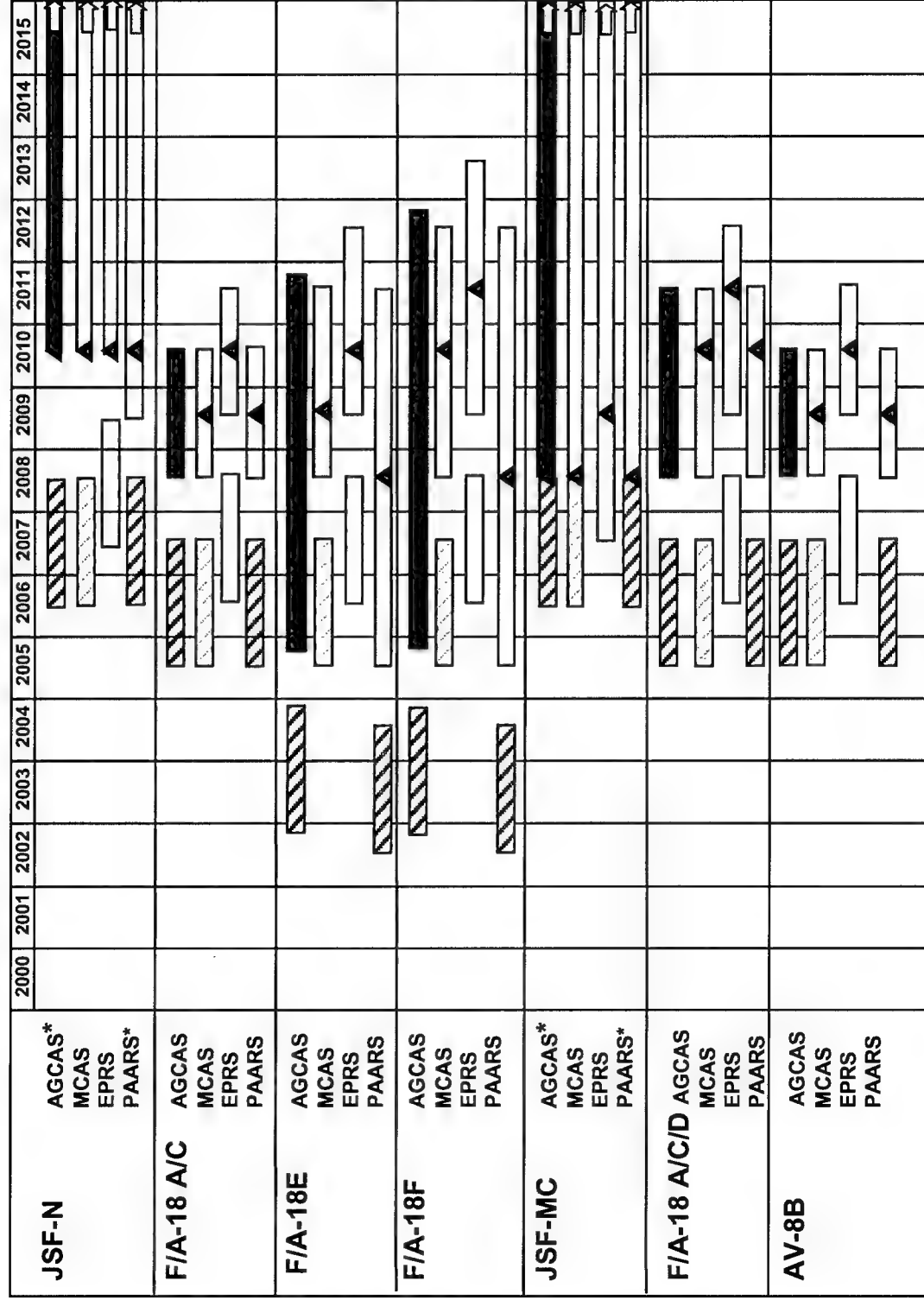


This chart uses the same methodology applied to Air Force aircraft on the previous chart to produce a nominal safety system implementation schedule for Navy and Marine Corps fighters. In each case IDA determined a reasonable start date for EMD initiation for each system/aircraft combination based on the maturity of the technology and the associated research and development completed to date. A nominal 3-year EMD program was assumed for each alternative. Fielding was based on the initiation of production following completion of EMD. Production and installation capability was assumed to mirror the experience of other similar systems previously installed on the same fighter aircraft. The length of fielding time is a function of the number of safety systems produced on an annual basis and the ability of the logistics system to install these devices during normal aircraft upgrade activity (as previously discussed for the Air Force aircraft). Schedules for the new F/A-18E/F and JSF aircraft are based on the planned production schedule of the aircraft rather than safety system production timelines so as to allow installation on the production line rather than during some future product improvement cycle for the aircraft. The gap between EMD and production for the Navy version of the JSF reflects the fact that the EMD program would be run simultaneously with the Air Force and Marine Corps, but production

would occur in accordance with the current plans. For those aircraft already in the inventory, the production schedule is designed to allow modification to the full fleet of a specific fighter type in 3-6 years, depending on the size of that fleet.

AGCAS and PAARS, the two technologies for which most research and development is already complete, are deemed available for installation earlier than the other alternatives. In addition, rather than ramp mishap benefit from zero just prior to safety system implementation to full implementation on the date of the last aircraft modification, the study used the implementation midpoint (or the date the first aircraft leaves the production line for JSF and F-22) as the "safety benefit determination year" to calculate the benefits associated with each particular combination. Mathematically, the results are equal and the use of a safety benefit determination year helped clarify the calculation as well as illuminate the time necessary for a safety system to impact the mishap rates. Given normal EMD and production, the earliest a system can arrive in the field is 2005 and the full impact would not be felt until 2008.

Potential Safety Concept Implementation Schedule: USN/USMC



*If AGCAS deleted from JSF requirements

As part of the comprehensive review of the available historical Class-A mishap data conducted for this study, IDA devoted a significant effort to examining each accident and determining the potential mitigating effect, if any, of each safety concept for that mishap. The time period examined for each aircraft was from first flight through the end of FY98. This chart displays the results of the Class-A mishap mitigation review over the lifetime of the current fighters included in the study. In the top table, the estimated lifetime percentages of Class-A mishaps potentially preventable with the four mitigating technologies selected for detailed analysis (AGCAS, MCAS, EPRS, and PAARS) are shown for the five Air Force and three Navy/Marine Corps fighters. The bottom table lists the percentage of aircrew fatalities potentially avoided over the fighter lifetimes with the four mitigating technologies.

Of the four safety systems, the prediction of the preventable mishaps with PAARS was the most uncertain because that system is not automatic. The concept requires the pilot to recognize that he or she is in need of recovery before manually activating the system. In reviewing the mishaps, IDA initially determined whether or not a concept was capable of mitigating a specific mishap. Where mitigation was possible, IDA selected only a subset of mishaps for which mitigation was determined to be likely. Only those mishaps where mitigation was likely were included in the final count.

For PAARS, this meant only those cases where the team felt it was likely that a pilot would have initiated the recovery system prior to the aircraft entering an unrecoverable flight regime were counted. Evidence of pilot incapacitation or extreme channelization resulted in no mitigation contribution by PAARS.

EPRS figures, on the other hand, represent a maximum potential benefit since some of the EPRS Class-A preventable mishaps may still result in damage of a lower Class level depending on the landing surface, conditions, what caused the pilot to initiate the system (fire, explosion), and the cost of the aircraft recovery effort.

Derivation of the corresponding mishap rate reduction for the new aircraft (e.g., JSF and F-22) and production aircraft (e.g., F/A-18E/F) was estimated using the data shown here. The new and production aircraft was compared to the current aircraft in terms of their roles/missions, their training regimen, flying hour program, pertinent design features, safety systems (over time), and flight performance. The relevant similarities and differences from the current fighters examined were then used to judiciously select the most appropriate aircraft (or combination of aircraft) to use as a basis for projecting the new and production aircraft Class-A mishaps preventable with the four safety systems. A slide comparing JSF projected baseline mishap rates to the rates for current aircraft is included in Appendix A.

Results of Historical Fighter Class-A Mishap Review

Mitigating Technology	Percent Preventable Class-A Mishaps					
	F-16A-D	F-15A-D	F-15E	A-10A	F-117A	F/A-18A-D
Midair Collision Avoidance System (MCAS)	12	18	N/A	9	N/A	7
Auto Ground Collision Avoidance System (AGCAS)	19	15	29	39	17	7
Emergency Parafoil Recovery System (EPRS)	37	11	57	1	0	13
Pilot Activated Automatic Recovery System (PAARS)	3	4	14	6	N/A	4
						1

Mitigating Technology	Percent Preventable Aircraft Fatality/Disability					
	F-16A-D	F-15A-D	F-15E	A-10A	F-117A	F/A-18A-D
MCAS	9	13	N/A	6	N/A	9
AGCAS	15	11	17	33	15	13
EPRS	2	1	16	2	0	16
PAARS	2	2	5	3	N/A	2
						1

- Notes: - Preventable mishaps with PAARS much more uncertain (requires pilot initiation)
 - EPRS Class-A preventable mishaps may still result in Class-B- or C-level mishaps

IDA reviewed a number of additional safety concepts for inclusion in the more detailed review. Most would certainly have a beneficial impact on either a specific aircraft's mishap experience or on the overall fighter Class-A mishap rate. However, these concepts were not carried forward to the in-depth review either because their effects could not be estimated, they appeared to impact only a small fraction of the expected future mishaps, and/or the cost of implementing these systems compared to the value of mishaps averted appeared to be an order of magnitude or more greater than the four eventually selected for detailed analysis. For example, this study effort, like many others, reinforced the need for accurate data. Addition of new cockpit voice, video, and other data recorders would both add to the information available about mishap fighters as well as enable review of non-mishap operations and cockpit procedures to enhance safety. Unfortunately, the study team could find no cause and effect data linking recording devices in fighter cockpits to the prevention of a specific mishap. Experts agree that timely review of cockpit information would help identify emerging system or procedural problems and facilitate corrective actions before mishaps occur; however, without more specific data, the team could not develop estimates for the mishap reduction potential of cockpit recorders.

Data were available for assessing the Automatic Takeoff and Landing System, but such systems would have been targeted at the 5 percent of fighter mishaps that occur as a result of pilot-induced problems in the takeoff

and landing phase. This percentage is already less than half the percentages associated with the four higher mishap causal factors. Because the operational requirements for visual and overhead patterns to both handle the high volume of traffic associated with combat operations as well as to avoid potential threats to operating bases in and near combat zones are not compatible with automatic takeoff and landing systems, the number of mishaps that could be mitigated by such systems is further reduced. Achieving this mitigation would require a significant investment in both on-board automatic takeoff and landing technologies as well as in associated mobile ground support systems needed to accompany the aircraft when they deploy.

Similar screening was applied to the other concepts shown on this chart. Smart cockpit/virtual copilot systems would definitely reduce pilot load and improve performance both in normal operational flight as well as during aircraft emergencies. Designing such systems and identifying past mishaps that they would have prevented is much more problematical. It was difficult to find more than a handful of mishaps where the inclusion of smart cockpits would have made the difference in saving an aircraft.

The Automatic Pilot Ejection System (APES) offers the potential to save pilots who are unable to eject prior to aircraft impact in an uncontrollable situation. Russian Vertical Take Off and Landing (VTOL) aircraft have this feature. The down side is that unlike an AGCAS system, the APES aircraft will still be lost. At the same time, the cost of a single false alarm for this system is much greater than for other technologies.

Other Concepts Examined Qualitatively

- **Fighter cockpit voice, video and data recorders**
- **Automatic Takeoff and Landing System**
- **Smart Cockpit/Virtual Copilot System (VCS)**
- **Automatic Pilot Ejection (APE)**
- **Automatic Departure Surveillance-Broadcast (ADS-B)**
- **Terrain Awareness Warning System (TAWS)**
- **Pilot monitoring (Smart Flight Suit)**
- **Aircraft monitoring**
- **Other sensors (laser vibrometry, audio sensors)**
- **NASA Initiatives(Human Error Modeling, Weather Hazard Detection/Mitigation, Accident Mitigation)**

The Automatic Departure Surveillance-Broadcast (ADS-B) system is currently used by several airlines and could be effective in preventing midair collisions for fighters on navigational sorties. However, this technology is not capable of handling the in-flight training and maneuvering where most fighter midair collisions occur. Likewise, terrain awareness warning systems are already available in a number of aircraft including fighters, but experience shows that incapacitated pilots or those experiencing channelized attention are not able to recognize the warning and maneuver accordingly to avoid collision with the ground.

There are a number of promising technologies in the monitoring category, either of pilot performance to help determine physical and mental readiness for handling high-task portions of a flight, or of aircraft system health. For example, a simple feedback loop that queries the pilot after high-G maneuvering could be incorporated with AGCAS or an automatic PAARS system to recover aircraft at altitude rather than waiting to near impact when it might be too late. Many current built-in test items already provide periodic checks of system health, but the new micro-electric mechanical system (MEMS) technology will significantly expand this capability. Unfortunately, at this point it is too early to tell whether such systems will detect a potential catastrophic failure before an impending mishap. Other sensors with advanced audio or laser vibrometry capabilities have been specifically postulated to be able

to determine imminent engine failures. Research will be the key to proving the ability of such systems to provide better prediction of engine problems, but to date none of these technologies has been reliably demonstrated.

In addition to specific military concepts and technological alternatives, the team reviewed a number of NASA safety study initiatives. These include research into human error modeling, which might lead to new training techniques; operational, maintenance, or controller procedures; or other supervisory-enhancing activities. The current effort is focused on when and why humans make errors. While the findings from such studies could be the basis for new initiatives, the work is yet not mature enough to provide such direction. NASA is also investigating ways to provide better ground and airborne detection of weather hazards. Once identified, pilots will have a chance to avoid them completely or at least be better prepared for their effects. Again, this research will need more time to generate specific concepts that could be applied to the military fighter force. Finally, NASA is looking at ways to mitigate the damage associated with a mishap after it occurs. For example, there might be ways to cause fuel to become inert after a collision, thus reducing the loss and damage due to fire and explosion. While all of these initiatives have long range potential for either reducing the number of mishaps or mitigating the resulting damage, none is technologically mature enough at this point to enable even low confidence projection of their potential mishap prevention effects.

Other Concepts Examined Qualitatively

(Continued)

- **Fighter cockpit voice, video and data recorders**
- **Automatic Takeoff and Landing System**
- **Smart Cockpit/Virtual Copilot System (VCS)**
- **Automatic Pilot Ejection (APE)**
- **Automatic Departure Surveillance-Broadcast (ADS-B)**
- **Terrain Awareness Warning System (TAWS)**
- **Pilot monitoring (Smart Flight Suit)**
- **Aircraft monitoring**
- **Other sensors (laser vibrometry, audio sensors)**
- **NASA Initiatives(Human Error Modeling, Weather Hazard Detection/Mitigation, Accident Mitigation)**

In addition to technological solutions, IDA postulated a methodology for investigating how new organizational concepts, Service policies, operational procedures, or training activities might impact the Class-A mishap rate. This chart outlines some of the key factors that would be involved in such an investigation. It draws upon the insights of leaders of operational units who have suggested that a number of variables--including the attitude, continuity and experience of their aircrews, maintainers, logisticians, and supervisors--play a major role in the safety of flight operations. In addition, they suggest that the age, health, and condition of their people and equipment are also part of the equation. Other variables, such as the unit climate as well as its culture, morale, and leadership have all been cited as playing a significant role in past mishaps, as have been a number of other factors listed on this chart. While any of these factors at the right time and under the right circumstances can become the key variable in a chain of events leading to a major mishap, there has not been a fully comprehensive effort in military aviation to gather all the data necessary to clarify how these factors work together to determine a hazard potential. The Services and safety centers have done an excellent job of collecting data regarding actual mishaps. What is missing is how the human factor variables associated with a specific mishap

compare to the rest of the Service population (both at the unit level and across the force) and how a change in these variables across the population can influence the mishap rate through time.

Operators and supervisors agree that attention to human factors is a vital part of any effective safety program. Gathering the right data to fully quantify the impact of specific human factors for a significant time period from the past requires a major investment in resources. For example, for a single type of fighter aircraft, the research team would want to know the operational characteristics of at least a cross-section of units operating the mishap fighter to include the capabilities, age, and health of assigned people and equipment, as well as details about unit, leadership, and supervisory attitudes concerning risk, safety, and mission accomplishment and how all these variables changed through time. It may not be possible to generate such data at this point and, even if it were, the constant cycles of personnel movement and operational activity might wash out the full impact of key variables. In any case, a detailed investigation could be pursued at some point, but the time frame and resources available for this study put the creation of the desired database and the ensuing analysis of these important human factors beyond the scope of this effort.

Human Factor Effects

- Must first normalize for new aircraft/improved safety technology
- Variables include operational, logistics and materiel factors:
 - Aircrew, maintainer, logistician, supervisor continuity/experience at unit, base and fleet levels
 - Includes total relevant experience on like-systems/aircraft, missions and positions as well as aircraft-specific experience and type, frequency, and currency of training
 - Age, health and condition of systems and people
 - Overall and critical position manning
 - Unit climate, culture, morale and leadership
 - Operational and personnel tempo
 - Training program, mission profiles
 - Inspection cycle, parts availability, logistics system responsiveness
 - Weather, time of day, and other environmental factors

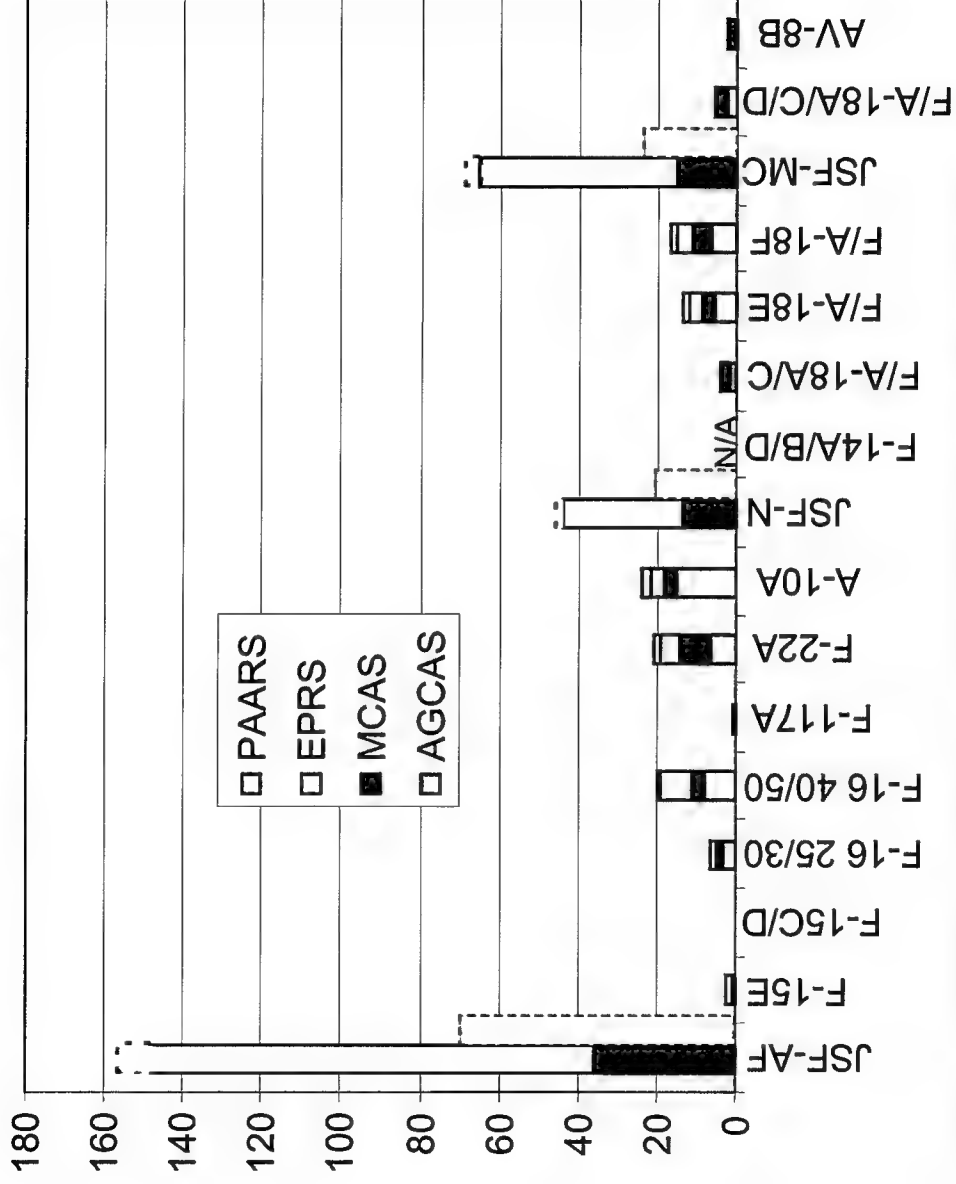
Could be a major contributor to mishap prevention, but detailed database for quantitative analysis not currently available

This slide displays the number of aircraft that can potentially be saved by each of the four safety systems examined in detail by the study. The numbers reflect the implementation schedules previously shown and the estimated fraction of Class-A mishaps preventable by each safety system on each aircraft. The data is displayed in a stacked bar chart format with the contribution of each safety system on the aircraft partitioned separately. All three versions of the JSF are presently planned to have an AGCAS system, according to the current draft JORD. Since at the time of this study final JORD requirements for avionics and flight controls were still under debate, the dashed lines next to the stacked bars for the JSF are provided to show the estimated number of aircraft that would have been lost if the system was not included in the JSF baseline. Technically an AGCAS system could incorporate PAARS functionality as a subsystem, eliminating any value of a separate PAARS capability. Therefore, the PAARS results for the JSF are also presented with dashed lines, showing how many aircraft could be saved with PAARS only if AGCAS (with PAARS functionality) is not part of the JSF baseline.

Since JSF is expected to be the backbone of the fighter fleet over the next 50 years with by far the greatest numbers of operational aircraft, there is no surprise that the analysis shows the greatest number of aircraft potentially saved through the addition of the safety systems examined are the three JSF variants (particularly the Air Force version). Of the four safety systems examined, the EPRS shows the largest potential for averting aircraft destruction, primarily for the single engine JSF where engine failures would otherwise most likely result in aircraft destruction. The envisioned MCAS system offers the potential for a significant number of aircraft saves for both the JSF and current fighters even though only fighter midair collisions between fighters of the same type are averted. The AGCAS system also offers the potential for saving a considerable number of current fighters. Only a relatively few potential aircraft saves are forecast for the PAARS system.

The N/A for the F-14 reflects the fact that it is currently being planned for retirement from service before the safety systems can be fully introduced in that fighter. The effect of PAARS on the F-117A is not shown since the system is already incorporated on that aircraft.

Potential Aircraft Saved with Selected Safety Systems



Note: JSF planned to have AGCAS (dashed lines indicate results without)

F-117 already has PAARS incorporated

F-14A/B/D retired prior to possible safety system introduction

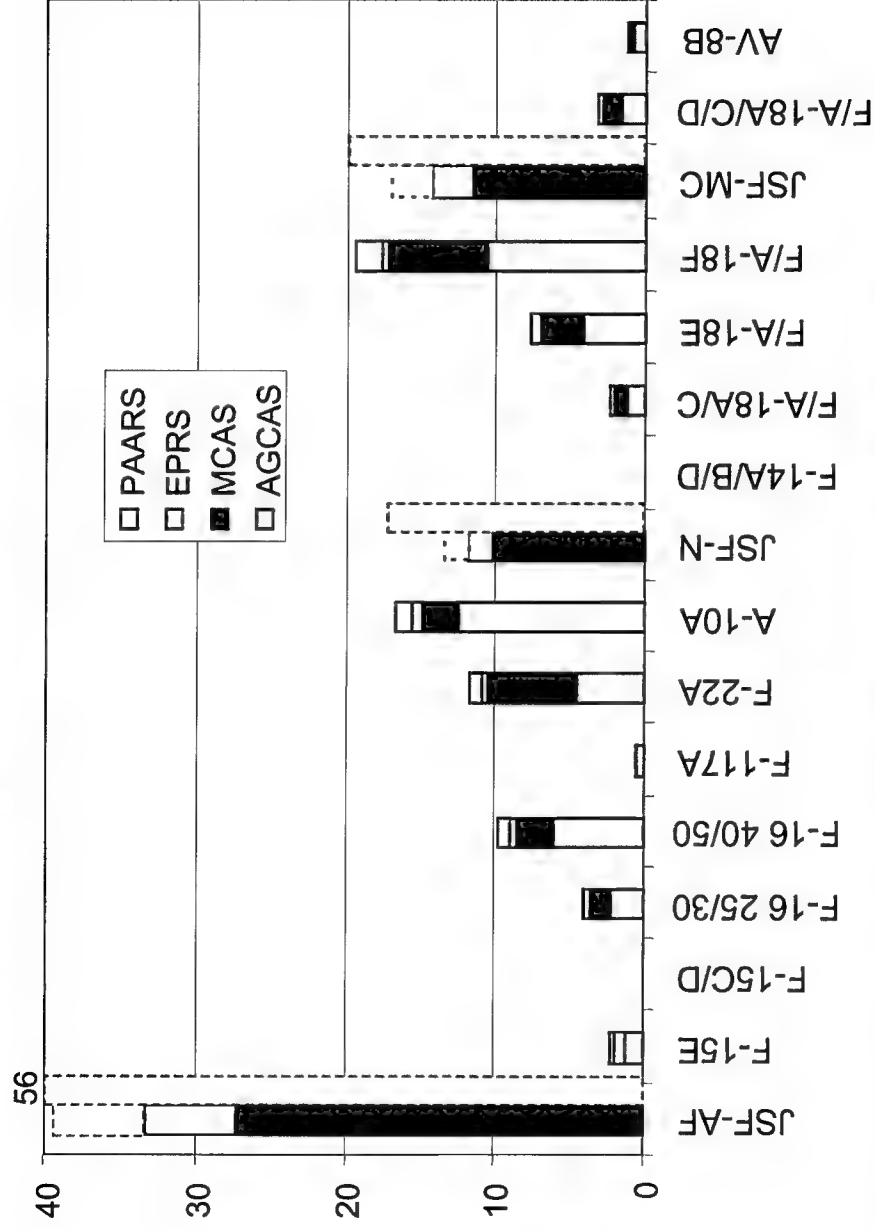
This slide illustrates the number of aircrew lives that can potentially be saved by the four selected safety system. The numbers reflect the implementation of schedules previously shown and the estimated fraction of aircrew fatalities preventable by each safety system on each aircraft. The data is displayed in a stacked bar chart format with the contribution of each safety system on the aircraft partitioned separately. Since the current draft JORD includes AGCAS as a threshold requirement for all three versions of the JSF, its impact is not included in the stacked bars. The dashed lines next to the stacked bars for each JSF indicate the estimated number of aircrews that would have been lost without the system. PAARS results for the JSF are also presented with dashed lines, showing how many aircraft could be saved with PAARS only if AGCAS (with PAARS function) is not part of the JSF baseline.

Since JSF is expected to be the backbone of the fighter fleet over the next 50 years with by far the greatest numbers of operational aircraft, there is no surprise that the analysis shows the greatest number of aircrew lives potentially savable through the addition of the safety systems examined are associated with the three JSF variants (particularly the Air Force version).

Of the four safety systems examined, the AGCAS shows the largest potential for averting aircrew fatalities, primarily with the JSF. Both the AGCAS and MCAS concepts offer the potential for a significant number of aircrew saves for current fighters with MCAS saves exceeding AGCAS for the air superiority F-22A. The EPRS system also offers potential to save a considerable number of JSF aircrews--in particular those mishaps where pilots currently wait too long to eject in an attempt to save the aircraft. An EPRS capability may encourage pilot ejection since aircraft damage would be mitigated by the parafoil recovery capability. The chart shows only a relatively few potential aircrew saves associated with the PAARS system.

The N/A for the F-14 again reflects the fact that it is retired from service before any safety systems can be fully introduced. The effect of PAARS on the F-117A is also not shown since the system is already incorporated on the aircraft.

Potential Aircrew Lives Saved With Safety Systems



Note: JSF planned to have AGCAS (dashed lines indicate results without)
 F-117 already has PAARS incorporated
 F-14A/B/D retired prior to possible safety system introduction

This chart ranks combinations of aircraft/safety concepts in terms of the number of aircraft and aircrews that could potentially be saved. Only the top 10 combinations are shown. The bold-face combinations indicate current or production aircraft while combinations in italics represent future (F-22A or JSF) aircraft.

All versions of the JSF (CTOL, CV, and STOVL) were grouped together in this chart because safety system implementation for these aircraft would likely be linked. In addition, other like aircraft whose safety concept implementation approaches would most likely be coupled, such as the Navy F/A-18E and F, and the Navy F/A-18A/C and Marine Corps F/A-18A/C/D, are also combined. The F-16s were kept separated into the older Block 25/30 and newer Block 40/50 versions because their disparate flight control system designs, among other reasons, necessitate different safety system installation approaches, estimated costs, and future mishap projections.

As expected, the JSF (all versions combined) dominates the top-10 rankings for both aircraft and aircrews potentially saved. The asterisked JSF entries reflect the fact that an AGCAS system is currently specified as a requirement in the JSF Joint Operational

Requirements Document and therefore its mishap prevention capability is already included in the projected JSF Class-A mishap rates. If AGCAS was omitted, the estimated mishap rate associated with aircrew lives lost would change as well, as shown on the preceding charts. In that case, implementation of the AGCAS would be ranked second in potential aircraft saved and first in potential aircrew saved. With no AGCAS, PAARS would become a highly desirable safety concept for the JSF, ranking fourth in potential aircraft saved and sixth in aircrew saved. If a pilot-activated recovery feature is included as part of the JSF AGCAS, a separate additional PAARS would have no additional beneficial impact.

Although safety systems on new aircraft dominate the rankings, with F-22 MCAS and AGCAS joining the JSF in the top 10, the chart shows that adding certain safety systems to selected current aircraft, even with the time delays associated with EMD and production, could provide a return in terms of potential aircraft and aircrew saved. In particular, AGCAS on F-16 Block 40/50, F/A-18E/F, and A-10 aircraft has a significant potential for saving aircraft and aircrews.

Aircraft and Aircrew Saved Rankings

Ranking	Aircraft	Aircrews
1	JSF:EPRS	JSF:AGCAS *
2	JSF:AGCAS *	
3		F/A-18E/F:AGCAS
4	JSF:PAARS *	A-10A:AGCAS
5	A-10A:AGCAS	JSF:PAARS *
6	F/A-18E/F:AGCAS	JSF:EPRS
7		
8		F-16 40/50:AGCAS
9	F-16 40/50:EPRS	
10	F-16 40/50:AGCAS	F-22:AGCAS

AGCAS



EPRS

PAARS

BOLD-Current/Production A/C

ITALIC-New A/C

* - Indicates ranking if AGCAS is deleted from JSF baseline; full AGCAS would incorporate PAARS feature

• Although JSF dominates rankings, A-10, F/A-18E/F, F-16 Block 40/50 and F-22 options have significant potential for saving aircraft and crews

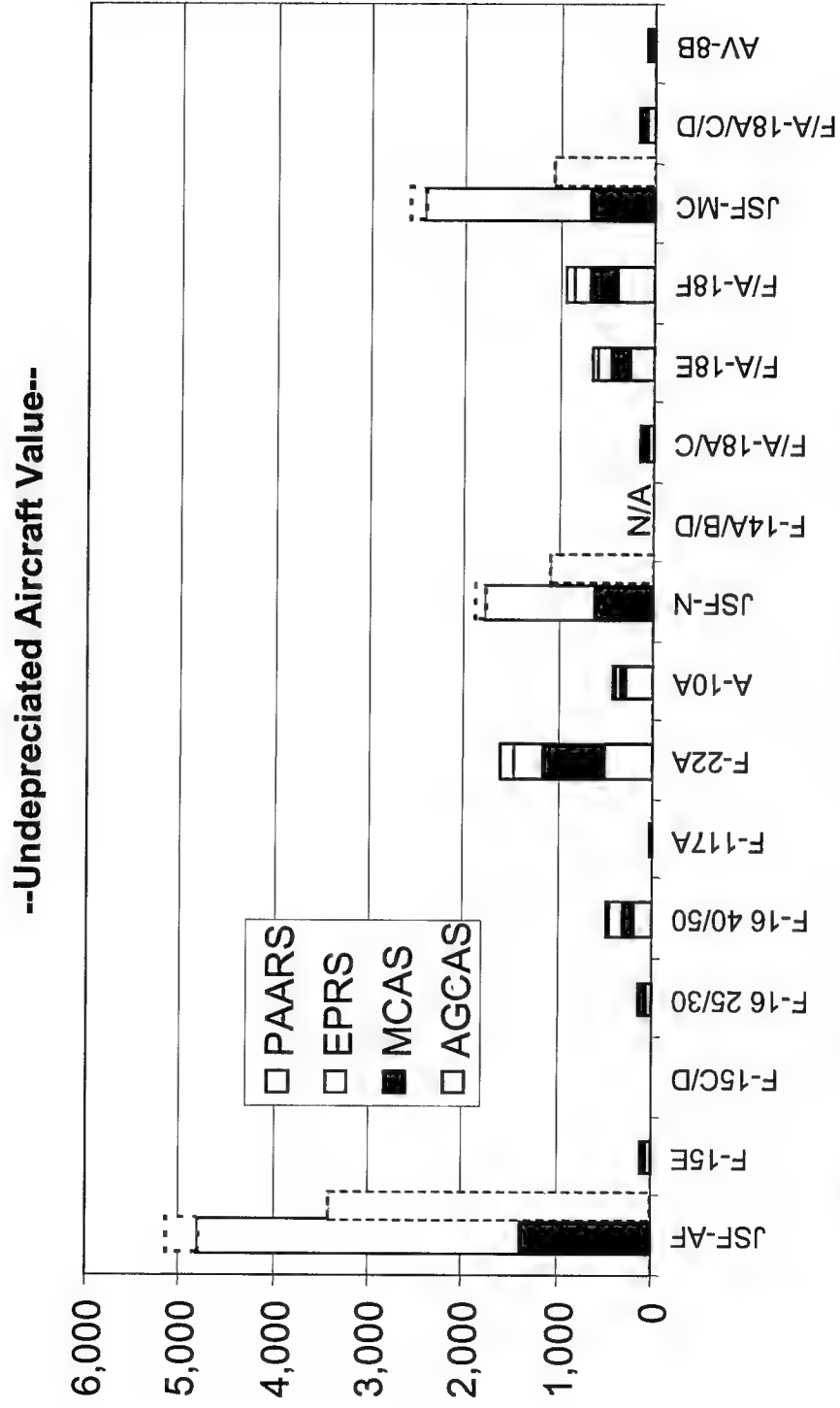
This slide shows the potential aircraft monetary value saved (in millions of FY00 dollars) for the four selected safety systems. The numbers reflect the estimate of aircraft losses that could potentially be prevented associated with the designated aircraft values that were presented previously. As a baseline, constant aircraft values (without depreciation) are used. A chart addressing aircraft value potentially saved using depreciation is included in Appendix A. The potential aircraft value saved is displayed here in a stacked bar chart format with the total contributions partitioned separately by fighter.

Because the JSF is expected to represent the largest overall value of fighter aircraft lost to mishaps through time, they also represent the greatest potential for saving. Consequently, the highest value of saved aircraft is associated with the new safety concepts on the three JSF variants (particularly the Air Force version). The next highest source of potential aircraft value savings is with the F-22A and F/A-18E/F. The dashed lines next to the stacked bars for the JSF indicate the estimated aircraft

value that would have been lost if the AGCAS system is not included as currently required in the draft JORD. The dashed PAARS lines indicate the value of saved JSF aircraft if an AGCAS system is not already part of the JSF configuration.

Of the four safety systems examined, EPRS shows the highest potential for saving aircraft value, primarily for the single engine JSF. However, while EPRS may avert aircraft destruction, the full aircraft value savings may not be attainable due to the cost of recovery and repair that may ensue. AGCAS offers a significant amount of aircraft value savings, primarily for the F-22 and F/A-18. If omitted from the JSF requirements, AGCAS would be elevated to nearly match the EPRS concept in value savings as shown by the dashed lines. MCAS is the next highest aircraft value saving concept, primarily for the JSF and the F-22. PAARS is projected to provide only a relatively small aircraft value savings due to the small number of mishaps the system is forecast to impact.

Monetary Value of Potentially Saved Aircraft (\$M FY00)



Note: Full value savings with EPRS may not be attainable.

While the value of damaged or destroyed aircraft is a major component of the cost of any military aviation mishap, there are a number of other costs associated with mishaps. Key among these is the value of lost aircrew. For mishaps that result in injuries, specific costs can be calculated based on the medical care provided and time lost for recovery. For more serious mishaps that result in a partial or permanent disability, a dollar loss can be calculated in terms of medical care as well as salary and disability payments generated over the remaining lifetime of the aircrew. Direct cost associated with a fatality is actually lower than that for a permanent disability, since salary and disability payments over the remaining life of the aircrew are not required. However, the government is still directly liable for insurance, recovery and burial expenses. In addition to direct costs, indirect costs associated with early retirement or death of a trained aircrew should also be included, which means adding some fraction of the total investment necessary to produce an aircrew member of equal experience to the direct costs (e.g., replacement training costs).

For several years, DoD manuals have directed the use of \$1.1 million to estimate the cost of a lost pilot and \$1.3 million for a permanent disability. The expense of undergraduate pilot training, fighter-specific training courses, and other schools, deployments, and dedicated flying time is actually several times higher than these figures for today's fighter pilot. Experienced flight leaders carry an even higher investment in terms of training and other development activities that contribute to the level of

expertise they have at the time of the mishap. Included in the back-up slides is a calculation of fighter pilot value showing a direct investment cost of over \$10 million average per F-15/F-16 fatality for training and experience. IDA's methodology is flexible and can use any value associated with pilot injury or loss with the understanding that the higher the value placed on aircrew fatality, the more a mitigating safety technology can cost and still equate to the value saved. This study used \$10 million as the baseline for the full aircrew replacement costs.

In addition to the cost of aircrew, mishap expenses typically include the cost of the mishap investigation; the aircraft recovery (especially expensive for mishaps requiring underwater recovery); the repair and/or replacement of other government or civilian ground property, equipment, or aircraft damaged or destroyed; and a number of less quantifiable cost factors. This latter area includes the political dimension (low-level training and relations between nations can be directly impacted by mishaps in a foreign nation), public relations, and even morale factors that can impact recruiting and retention. Depending on when a mishap occurs, it can result in the grounding of an aircraft fleet or the denial of specific training leading to a loss of combat proficiency. Again, the methodology allows for any dollar amount to be used to estimate this additional value with the understanding that the higher the cost per mishap, the more that can be spent on safety concepts and still achieve break even. For the additional mishap value in this study, IDA used a baseline figure of \$1 million per mishap mitigated (except for EPRS, a system which reduces costs by saving aircraft, but does not eliminate the mishaps).

Other Mishap Costs

- **Aircrew**
 - **Fatality**
 - **Permanent Total Disability**
 - **Other (Less Severe) Injuries**
 - **Mishap Investigation Process**
 - **Aircraft Recovery Effort**
 - **Repair/Replacement of Other Military Property Destroyed**
 - **Repair/Replacement of Destroyed Civilian Ground Property or Aircraft**
 - **Others (Less Quantifiable)**
 - **Political (between nations, internal)**
 - **Public Relations**
 - **Recruiting/Retention**
- \$10M used per total disability or fatality avoided (when included)**
- \$1M used per mishap avoided except EPRS (when included)**

The total monetary value saved from mishaps averted with the four safety systems evaluated is illustrated in this slide. The numbers add the value of the aircraft potentially saved with the additional mishap costs described on the previous slide. As a baseline, constant aircraft values (without depreciation) are used. The total value of averting mishaps taking into account aircraft values with depreciation is illustrated on a slide in Appendix A. The other mishap cost elements (aircrew and additional) are not depreciated. The data uses FY00 dollars and is displayed in a stacked bar chart format so the contribution of each safety system to the total mishap value saved can be seen separately.

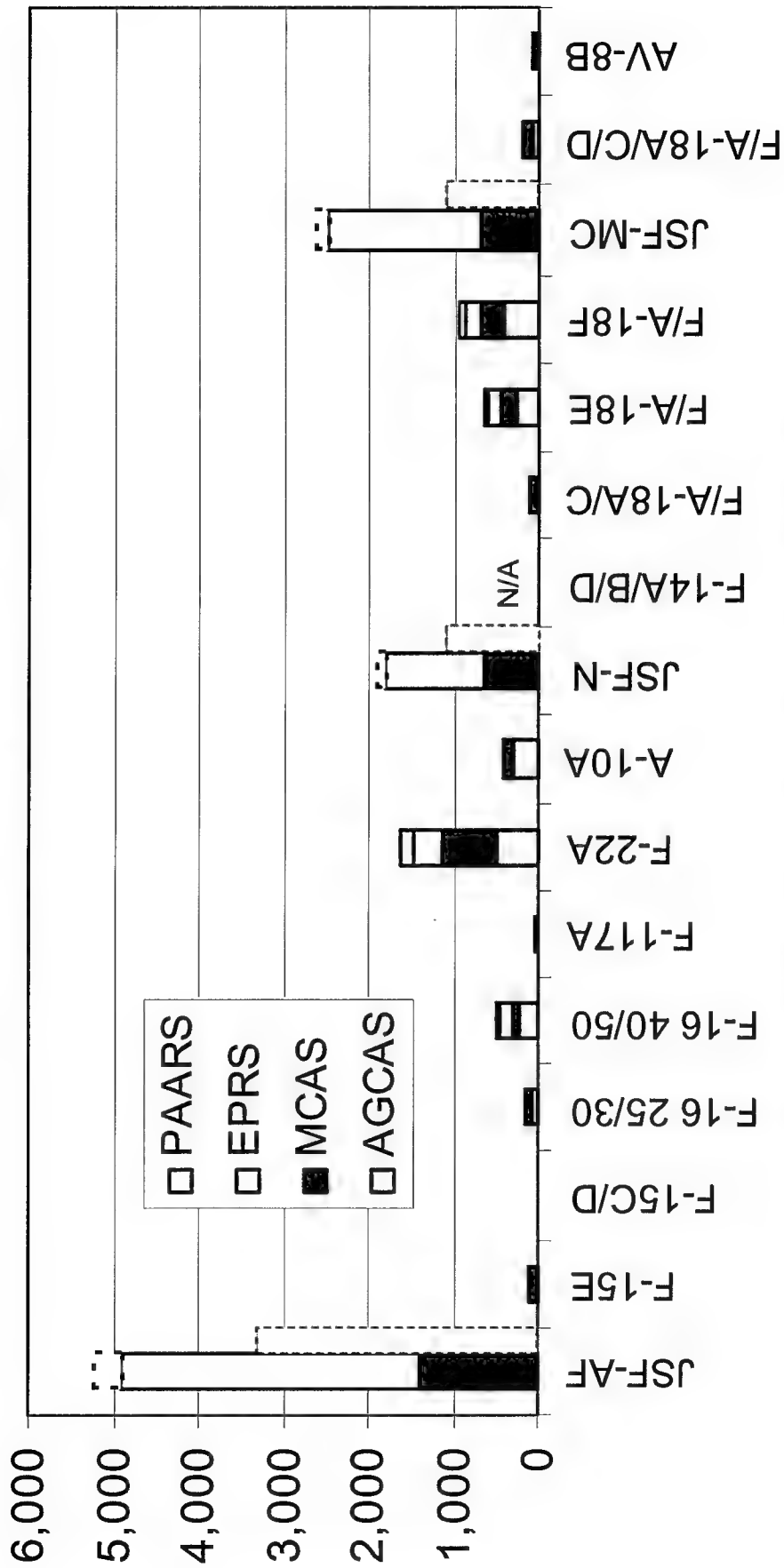
Overall, the values depicted in this chart are only slightly greater than those shown in the previous chart which addressed aircraft value without the additional associated mishap costs. The main differences are with those fighters which have a disproportionately higher loss of life associated with aircraft loss or those systems that address causes that are correlated with a higher fatality rate. The A-10A falls in the former category since its low level operational mission and the high number of fatalities associated with controlled flight into ground situations cause it to have a significantly higher fatality per mishap ratio than most other fighters. The AGCAS and MCAS concepts fall in the latter category, since collisions with the ground and with other aircraft generate the highest percentage of Class-A mishap fatalities. Total monetary savings for that aircraft and those systems are therefore higher than with the aircraft-value-only component.

As with the earlier chart, this one shows that the largest total monetary value associated with averting mishaps is related to the three JSF variants (particularly the Air Force version). The next highest source of total mishap value savings is with the F-22A and F/A-18E/F. The dashed lines next to the stacked bars for the JSF again indicate the estimated number of aircraft that would have been lost without the AGCAS system (which is currently required on the aircraft).

Of the four safety systems examined, EPRS shows the largest potential for total mishap value savings, primarily for the JSF. However, while EPRS may avert aircraft destruction, the full mishap value savings may not be attainable due to the cost of recovery and repair that may ensue as well as other costs associated with less than Class-A damage to other assets, political ramifications of an unscheduled parafoil recovery, and the resultant public relations and morale impacts. AGCAS offers a significant amount of total mishap value savings, primarily for the F-22 and F/A-18. If omitted from the JSF requirements, AGCAS becomes the second largest source of total mishap value savings. Again MCAS provides the next highest total value savings, primarily for the JSF and the F-22. AGCAS and MCAS both offer potential for significant total mishap value savings for both new and current fighters. PAARS seems to generate only a relatively small total mishap value savings due to the small number of aircraft mishaps the system is forecast to impact.

Total Monetary Value of Mishaps Potentially Averted (\$M FY00)

--Undepreciated Aircraft Value--



Note: Full value savings with EPRS may not be attainable.

Using the costs described on the previous slide and the value associated with averting mishaps derived earlier, IDA calculated a total potential net benefit for the four safety systems evaluated. The results are shown here. The numbers are the sum of the value of aircraft saved and the designated additional mishap costs minus the total safety system implementation costs. The baseline shown here uses the constant aircraft values without depreciation, although a chart with depreciated aircraft value is included in Appendix A. The data displayed is in a grouped bar by aircraft format so the net benefit of each safety system and aircraft combination can be seen separately.

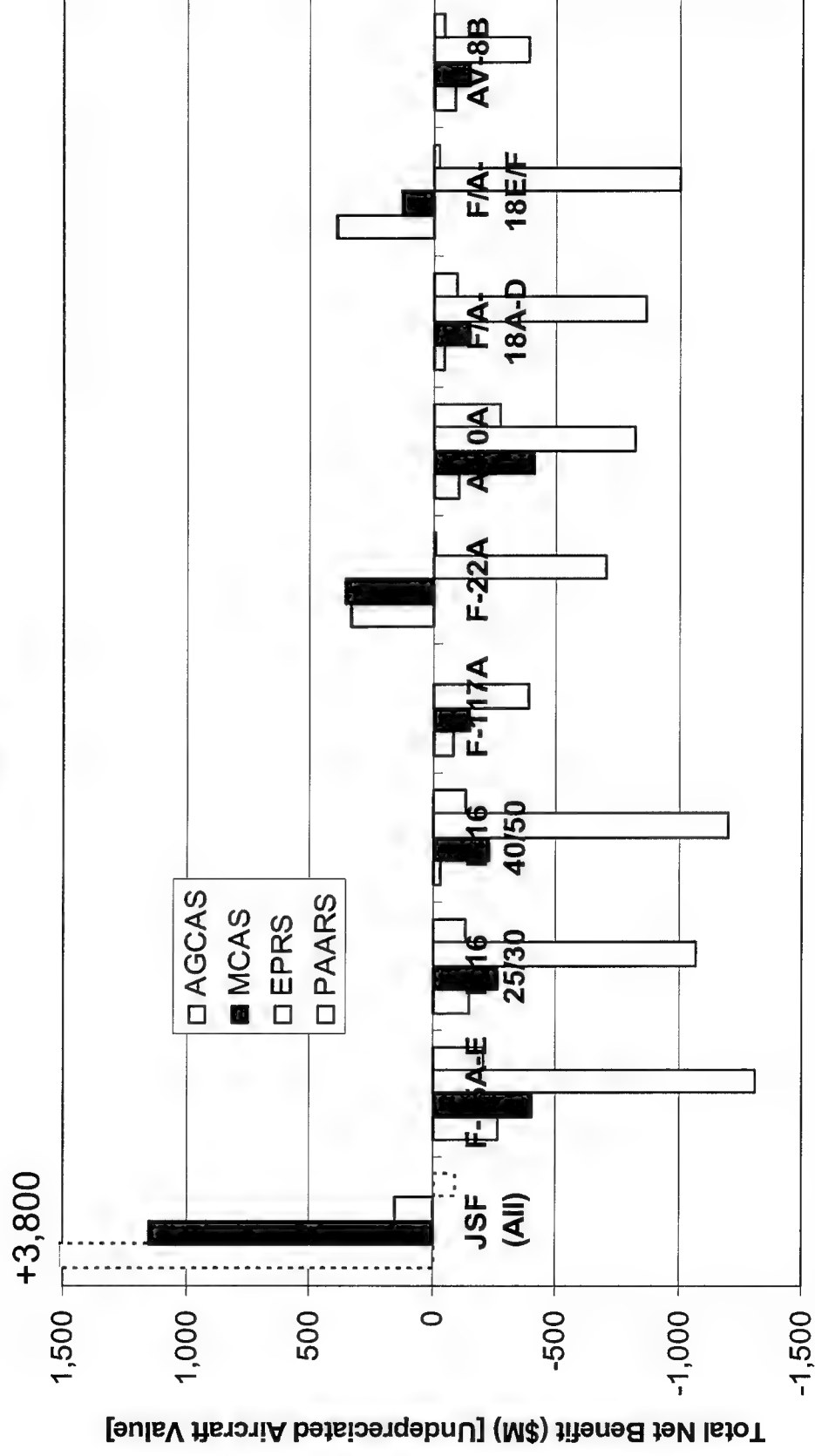
Overall, there are only a relatively small number of aircraft/safety system cases that yield positive total net benefits. The largest potential net benefits by far are for the JSF with AGCAS (if not included in the baseline JSF configuration)⁷ and then JSF with MCAS. The next highest groups of total net benefits are the JSF with EPRS, F-22 with AGCAS, F-22 with MCAS, and F/A-18E/F with AGCAS. The magnitude of the net benefits is sensitive to the various assumptions of aircraft and aircrew value, other mishap costs, and depreciation, although the rank

⁷ In reviewing this document, an Air Force official asserted that because the flight profile of the JSF will be at higher altitudes than the systems it is replacing, it should experience fewer CFIT mishaps than projected in this study. Even using that official's estimate of CFIT losses (half that are shown here), the value of avoiding the remaining projected losses due to G loss of consciousness and pilot disorientation is over three times greater than the cost required to install AGCAS on the JSF.

order remains fairly constant across all aircraft/system combinations once those values and costs are determined. For example, AGCAS on the F-16 Block 40/50 shows a slight negative number in terms of net benefit on this chart, even though it is highly ranked in terms of aircraft and lives saved. Were the replacement value of the aircraft specified to be \$24 million rather than the \$19 million used in this analysis, the system would break even in terms of value saved equaling system cost. Likewise, if a full engineering study finds IDA's implementation costs conservative, a recalculation with more accurate costs might push F-16 AGCAS into the positive net benefit arena.

Of the four safety systems examined, the MCAS and AGCAS (especially for the JSF) show the largest potential for total net benefits, primarily with the new and production JSF, F-22A, and F/A-18E/F aircraft. While aircraft destruction can be averted and high value saved with EPRS, the total net benefits are negative in all cases except for the JSF due to the high implementation costs. In a similar way, the implementation costs of PAARS outweigh the total mishap value savings, resulting in a negative total net benefit for all the aircraft considered despite the fact that implementation costs are lower than all other concepts.

Potential Net Benefit With Safety Systems (\$M FY00)



Note: JSF planned to have AGCAS (dashed lines indicate results without)

The previous charts were calculated in present value terms, collapsing all cost and value data across the service life of each aircraft/concept combination into a single column to facilitate comparison. A more detailed analysis can also be performed by calculating annual costs and value information across the lifetime of each aircraft, as was accomplished in IDA's earlier F-22 study.⁷ This chart provides a sample of that study's equal effectiveness methodology by showing how the costs and benefits of the analyzed systems could be applied to the Air Force version of the Joint Strike Fighter. The curves represent the cumulative net benefit of each system incorporated on the AF JSF through the aircraft's service life. Points on each curve show the cumulative sum of costs and benefits up to the date selected and where they fall with respect to the breakeven line.

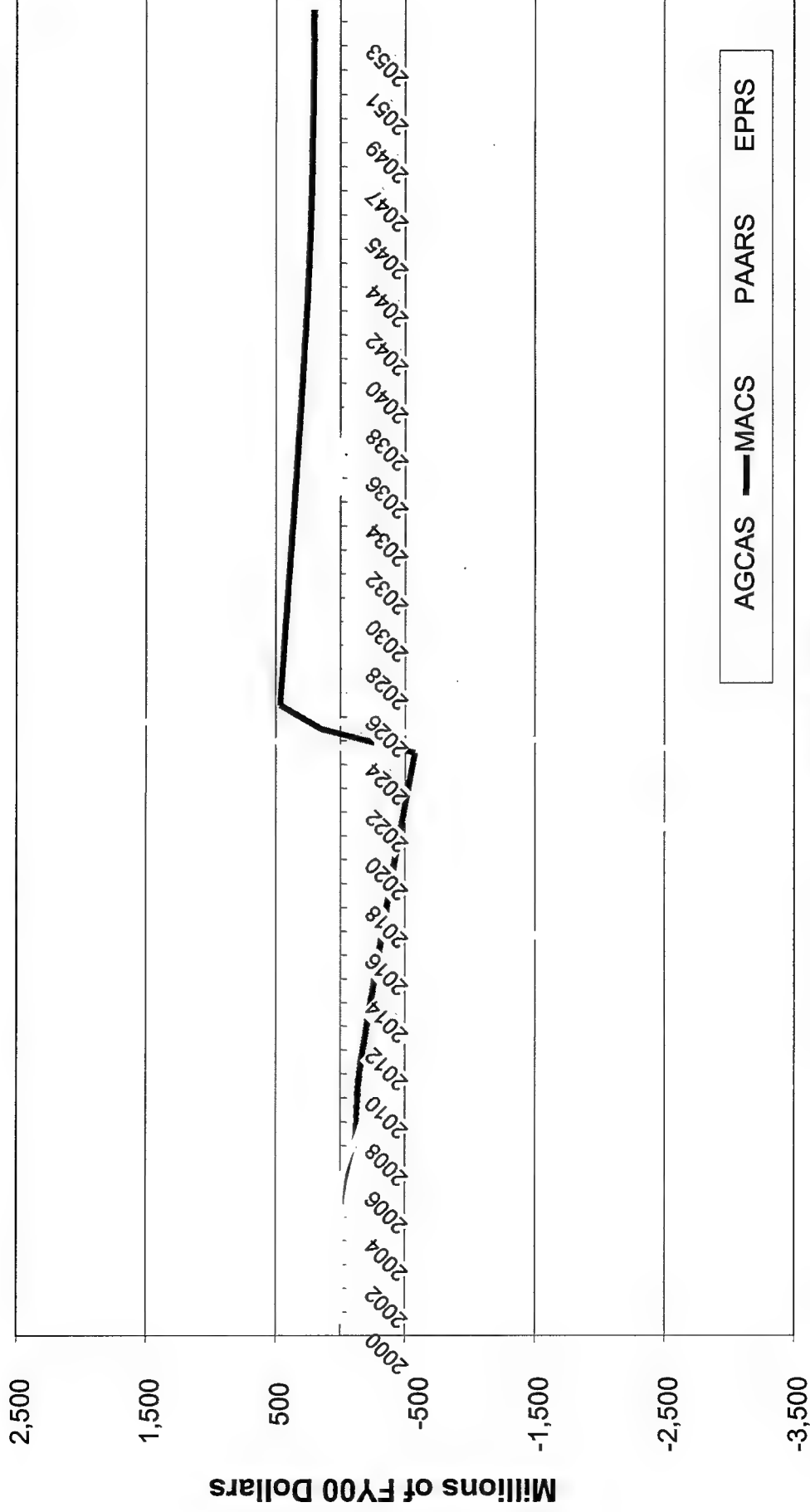
Development and production costs for the safety systems start to accrue long before the aircraft is delivered, while benefits do not begin until later. For simplicity, the only benefit illustrated here is the reduced buy of total aircraft purchased by the Air Force which is enabled by each specific safety system. With a smaller number of JSFs lost to mishaps, the same average aircraft fleet size

and the same combat effectiveness through time can be assured with a smaller total aircraft buy. The jump in net benefit in the mid 2020s reflects this and the fact that the reduction is implemented by taking the projected aircraft savings out of the last lot of purchased aircraft.

The relative costs of implementing each system are reflected in the slope of the benefit curve and the low point on the chart. AGCAS is highlighted as attaining the highest relative benefit and retaining its large positive value through last several years of JSF service life. MCAS is slightly more expensive and recovers to a position about one-third the value of AGCAS, while remaining positive from that point until the aircraft is retired. The EPRS figures show a much higher cost early in the program and then a recovery above break-even for several years before the cost of O&S drives it back below the line. This negative end point for AF JSF was not evident in earlier charts because the lower savings associated with EPRS on the AF version of the JSF were combined with the much higher savings associated with EPRS on the Marine Corps version of the aircraft. Finally, as noted earlier in the report, PAARS accumulates the least cost of any of the systems, but despite this, even its maximum benefit point does not take it above break-even.

⁷ *Costs and Benefits of the Installation of Certain Flight Safety Systems on the F-22A Aircraft*, IDA Paper P-3487, October 1999, UNCLASSIFIED. See particularly Chapter VII, Section B.

Present Value of Net Benefits for Concepts Implemented on Air Force JSF



This chart converts the graphical representation of the Value of Mishaps Averted and Total Net Benefit charts into a simple rank order formulation to show how the various aircraft/safety system combinations are ranked for these two measures of merit. JSF options continue to dominate the rankings, although the cost factors associated with EPRS cause the JSF version of that system to drop out of the top five when cost is added to create the total net benefit measure. Likewise, the relative cost of PAARS on the JSF causes it to drop out of the 10 in the total net benefit ranking. The other two EPRS systems identified in the value of mishaps averted top 10 (F/A-18E/F and F-22A) are likewise dropped from the top 10 when cost is added to value to create the net benefit measure.

In the net benefit ranking, AGCAS and MCAS combinations dominate, not only for the new JSF and F-22 aircraft but also for the production F/A-18E/F. The chart also shows that AGCAS options are preferred to PAARS

options for the same aircraft. Since the AGCAS can include a PAARS functionality as part of the AGCAS capability, the rank ordering and the net positive benefit measures associated with AGCAS suggest that if a safety concept is pursued, total net benefit analysis favors the more capable AGCAS system over the less expensive (but less capable) PAARS.

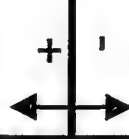
The F-16 Block 40/50 is also ranked in the top 10 of the total net benefit rankings. Although slightly negative in terms of value minus cost, it is the highest ranked of the current aircraft for the net benefit measure of effectiveness and, as shown previously, would result in reduced aircraft and aircrew loss. If the Department wants to pursue a technology option to impact the overall mishap rate of current fighters as soon as possible, this is the highest ranked option to pursue.

Value of Mishaps Averted and Net Benefit Rankings

Ranking	Mishap \$ Averted	Total \$ Net Benefit
1	JSF:EPRS	JSF:AGCAS*
2	JSF:AGCAS*	
3		F/A-18E/F:AGCAS
4	F/A-18E/F:AGCAS	
5		F-22A:AGCAS
6	JSF:PAARS*	JSF:EPRS
7	F-22A:AGCAS	
8		F-22A:PAARS
9	F/A-18E/F:EPRS	F/A-18E/F:PAARS
10	F-22A:EPRS	F-16 40/50:AGCAS
<div> <div>AGCAS</div> <div></div> <div>AGCAS</div> </div>		<div> <div>EPRS</div> <div></div> <div>PAARS</div> </div>

BOLD - Current/Production A/C
ITALIC - New A/C

* - Indicates ranking if AGCAS is deleted from JSF baseline; full AGCAS would incorporate PAARS feature



- Positive net benefit for JSF, F-22 options as well as F/A-18E/F
- Highest ranked nearest term options are AGCAS on F/A-18 and F-16

IDA's analysis indicates that new technologies can potentially reduce the number of fighter Class-A mishaps associated with both current and future aircraft. The study indicates that there are a number of cost effective solutions in the classic sense, since the investment in safety technologies to improve the new JSF and F-22A and production F/A-18E/F aircraft mishap rates can be offset by reducing the production run by the number of aircraft saved. This reduces the overall investment in these aircraft programs with no net loss in numbers available or fleet combat effectiveness. At the same time, even for aircraft whose production runs are already complete, safety options are available whose value in dollar terms comes close to covering the investment costs and for which significant numbers of aircraft and aircrew, lives can be saved. If the values attributed to the aircraft, aircrew, and other mishap costs are higher than those used by IDA, the net benefit equation for those options could swing into the positive net benefit range.

The IDA team also noted that the development of some safety concepts appears to follow a natural progression. For example, even though AGCAS on the JSF seems to offer the highest benefit in terms of lives saved and total net benefit, AGCAS itself has yet to be flown by any operational fighter unit. In order to fully develop AGCAS and gain aircrew acceptance for its effectiveness, it should be installed on an operational fighter such as the F-16 Block 40/50 at the earliest possible date. Any lessons learned in production or in operation can then be applied as it is introduced on other aircraft,

such as the JSF and F-22A. Such an approach would help prove the system's capabilities, ensure the most accurate cost estimates for other applications, as well as reduce the cost of installing it on later aircraft, thereby reducing the total cost of the system across all aircraft.

Likewise, producing a workable AGCAS system appears to be the right starting point for creating an effective MCAS system. The same computer controller and flight control interface that automatically avoids impending collision with the ground would be used to maneuver aircraft on a collision course away from each other. However, the IFDL on the F-22 may provide a means for a near-term limited MCAS (same type aircraft collision avoidance only) for that aircraft.

A final observation is that the ranking of aircraft/technology combinations depends directly on the metrics used. Preventing mishaps and saving crew lives puts a higher premium on adding systems to existing aircraft as shown on the chart. The Services apply cost effective measures for determining what systems should be added to which aircraft. The result is that most new safety systems do not surpass the break even point on existing aircraft given current measures of aircraft and aircrew value or else are deemed less important than combat-enhancement systems. However, if higher aircrew and aircraft values are attributed, not only could break even points be exceeded, but the addition of new safety systems may actually result in more aircraft and aircrew being immediately available when the nation needs them in time of war.

General Observations

- New technologies can reduce the number of fighter Class A mishaps
 - Some are cost effective in the classic sense while others prevent the loss of significant numbers of aircraft and aircrew
 - Some combinations build on and benefit from investment in others
- Ranking depends on metric used:

Ranking	Aircrew Saved
1	JSF:AGCAS*
2	
3	F/A-18E/F:AGCAS
4	A-10A:AGCAS
5	JSF:PAARS*

Example 1

A-10A:AGCAS ranked in top 5 for potential aircrew and aircraft saved but not in top 10 for net benefit due to low imputed dollar value of aircraft saved

Ranking	Net \$ Benefit
1	JSF:AGCAS*
2	
3	F/A-18E/F:AGCAS
4	F-22A:MCAS
5	F-22A:AGCAS

Ranking	Aircraft Saved
1	JSF:EPRS
2	JSF:AGCAS*
3	
4	JSF:PAARS*
5	A-10A:AGCAS

Example 2

JSF:EPRS ranked first for aircraft saved and mishap \$ averted but not in top 5 for net benefit due to high projected installation cost

Ranking	Net \$ Benefit
1	JSF:AGCAS*
2	
3	F/A-18E/F:AGCAS
4	
5	F-22A:AGCAS

In addition to the general observations provided on the previous chart, IDA developed specific observations for the four technologies considered in detail during the analysis. AGCAS on the JSF was clearly the most cost-effective system/aircraft combination. The results provide a solid basis for retaining this capability as a threshold requirement for the JSF program. In addition, AGCAS on the F-22A and F/A-18E/F were both highly ranked and offered an overall net positive benefit. Including AGCAS systems on these aircraft would save aircraft, lives, and dollars over the service life of these fighters. AGCAS could also save a number of aircraft and lives if installed on the F-16, the A-10, and the F/A-18A/C/D. While the monetary measures were not as compelling for these aircraft as they were for current production or new aircraft, they did indicate that AGCAS on these systems would provide the earliest opportunity for reducing Class-A mishap rates on current aircraft. In addition, since AGCAS has not been incorporated on any aircraft fleet to date, taking advantage of the research done on F-16 variants by installing it on the Block 40/50 version of the F-16 could confirm system effectiveness, enable more accurate cost estimation, and help develop operator buy-in before the system is incorporated in other fighters.

The study showed that MCAS appears to be a promising technology follow-on to AGCAS. Its high ranking and potential cost benefit value suggest that focused research in the limited-capability (same type aircraft only) system analyzed by this study would be beneficial, particularly for the F-22.

New sensors to enable a broader MCAS capability to detect and avoid all aircraft could yield a greater aircraft/aircrew savings as well as reduce overall investment in future fighter fleets. Because MCAS requires more research and development and would generally be fielded later than AGCAS, it would primarily apply to newer aircraft. On the other hand, if it can take advantage of the computer and flight control interfaces associated with AGCAS, it has the potential of being easily implemented in any aircraft that already has AGCAS installed at the time of MCAS production.

EPRS showed great promise in reducing aircraft destruction and was the only technology that was able to address engine failure and other reliability issues that currently result in ejection and loss of aircraft. While weight/drag penalties in wartime could be reduced by the use of a removable system, a number of issues still need to be addressed. Because of the system's broad applicability, the implementation and installation issues merit further study, particularly for use in the single-engine JSF.

Despite its relatively lower cost, the study indicated that PAARS does not provide sufficient mishap avoidance to yield a positive net benefit as a stand-alone program. Only if AGCAS is not implemented would such a system yield a positive net benefit for new aircraft, such as the JSF. Instead, the study suggests that it would be most beneficial if included as a part of AGCAS rather than as a unique, stand-alone system.

Safety System Summary

- AGCAS on JSF is the most cost-effective system/aircraft combination; solid basis for program requirement
 - High ranking and positive net benefit for F-22A and F/A-18E/F as well
 - While monetary measures are not as compelling, significant aircraft and aircrew savings result for A-10, F-16, and F/A-18A/D
 - Technological start point for MCAS; PAARS feature could be a subset
- MCAS appears to be a promising technology follow-on to AGCAS; investment in R&D program merits consideration
 - Primarily would apply to F/A-18 E/F, F-22 and JSF
- EPRS could greatly reduce aircraft destruction but implementation costs could be significant
 - Primary benefit to single-engine aircraft; merits further study for JSF
 - Weight/drag penalties minimized with removable system
- PAARS does not provide sufficient mishap avoidance to yield positive net benefit as stand-alone program, despite low cost
 - Primarily would apply to JSF if AGCAS is not implemented

This chart displays some of the recommendations that follow from the knowledge gained over the course of the study. Because of its high potential, research on AGCAS should be completed as quickly as possible and EMD for the Block 40/50 F-16 initiated. A full implementation plan could be included in the Air Force's 02 Program Objective Memorandum submission. This action would provide the fastest route to putting the system in the field, first on the F-16 to confirm cost and capability estimates as well as to build operator support. Getting the system into the field quickly will be the key to realizing the potential aircraft and aircrew savings associated with the technology. At the same time, AGCAS should be protected as a threshold requirement for the JSF and the implementation plan for the F-22A recommended by IDA's earlier study should be executed. In the earlier study IDA suggested AGCAS not be included in the earliest F-22 production lots since the developers and program managers were already stretched to implement a number of new systems and capabilities in the aircraft. However, by Lot 6 in 2006, the flight control and avionics systems should be stabilized, more extensive F-16 data available, and AGCAS could be added with the least risk to the F-22 program. As the system is proven in the F-16, it can also be extended to the F/A-18E/F program and additional analyses can be conducted to determine its suitability and payoff for the A-10 and other current fighters.

A second set of recommendations addresses MCAS. Functioning properly, AGCAS will provide a computer/flight control interface for automatically avoiding

predicted collision points with the ground. Therefore, pursuing the additional technology to use the F-22's IFDL, or other datalink capability such as the JTIDS, as a real-time input for midair collision prediction appears to have significant payoff and near-term application. In addition, investing in the research and development for other midair avoidance sensor technologies would ensure MCAS could eventually grow to cover midair situations beyond just two-thirds that involve same-type aircraft in maneuvering flight.

IDA also recommends that DoD continue to study EPRS with particular emphasis on understanding and reducing cost factors. In addition, DoD should consider facilitating the development of a standard mishap taxonomy to be used by all Services to improve their ability to share mishap insights and work together for technological and other solutions. Finally, DoD may want to pursue additional data-gathering activities. Currently, there is no systematic collection of data for the F-117 PAARS system. Providing an automated system to track system initiations, including flight conditions at the time of initiation through recovery maneuver completion, would provide a solid database for tracking when the system is used and the extent of its effectiveness. Whether or not it addresses PAARS, DoD may want to expand data gathering associated with mishaps to include collecting data on non-mishap operational, maintenance, and supervisory populations to facilitate comparison of mishap individuals with their peer groups and to develop a better understanding of the effects and implications of the human factors involved.

Recommendations

- **Complete research and begin EMD for AGCAS on F-16 Block 40/50**
 - **Submit full F-16 Block 40/50 implementation plan with 02 POM**
 - **Retain AGCAS as JSF threshold requirement and plan for implementation on F-22 (Lot 6, in 2006) and F/A-18E/F**
 - **As cost and capability are confirmed, perform detailed analysis to determine suitability for A-10 and other fighters**
- **Assess technical feasibility and cost of implementing near-term same-type aircraft MCAS for F-22 using IFDL**
 - **Monitor for possible introduction on F/A-18E/F and JSF**
 - **Support R&D investment in other midair avoidance sensor technologies for advanced MCAS applications**

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Appendix A

Back-Up Slides

Aircraft Mishap Definitions

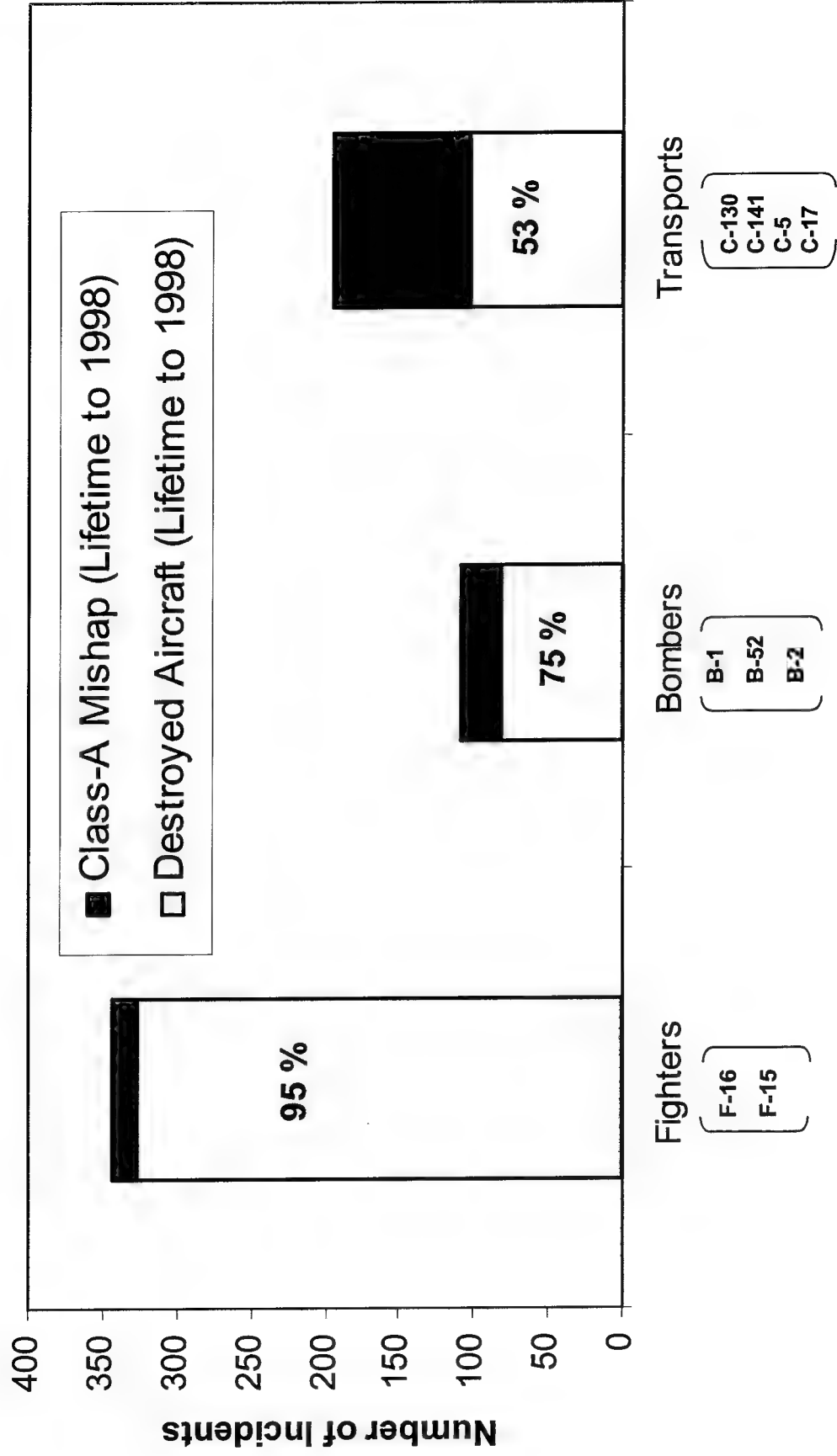
Mishap Classification	Definition [Aircraft Damage and/or Personnel Injury]
Class A	<ul style="list-style-type: none"> • Reportable Damage over \$1,000,000 • Fatality or Permanent Total Disability • Destruction of Aircraft
Class B	<ul style="list-style-type: none"> • Reportable Damage of \$200,000-\$1,000,000 • Permanent Partial Disability • Hospitalization of 3 or More Personnel
Class C	<ul style="list-style-type: none"> • Reportable Damage of \$10,000-\$200,000 • Injury Resulting in Lost Workday • Other*

Source: *Safety Investigations and Reports*, AFI 91-204, February 1998

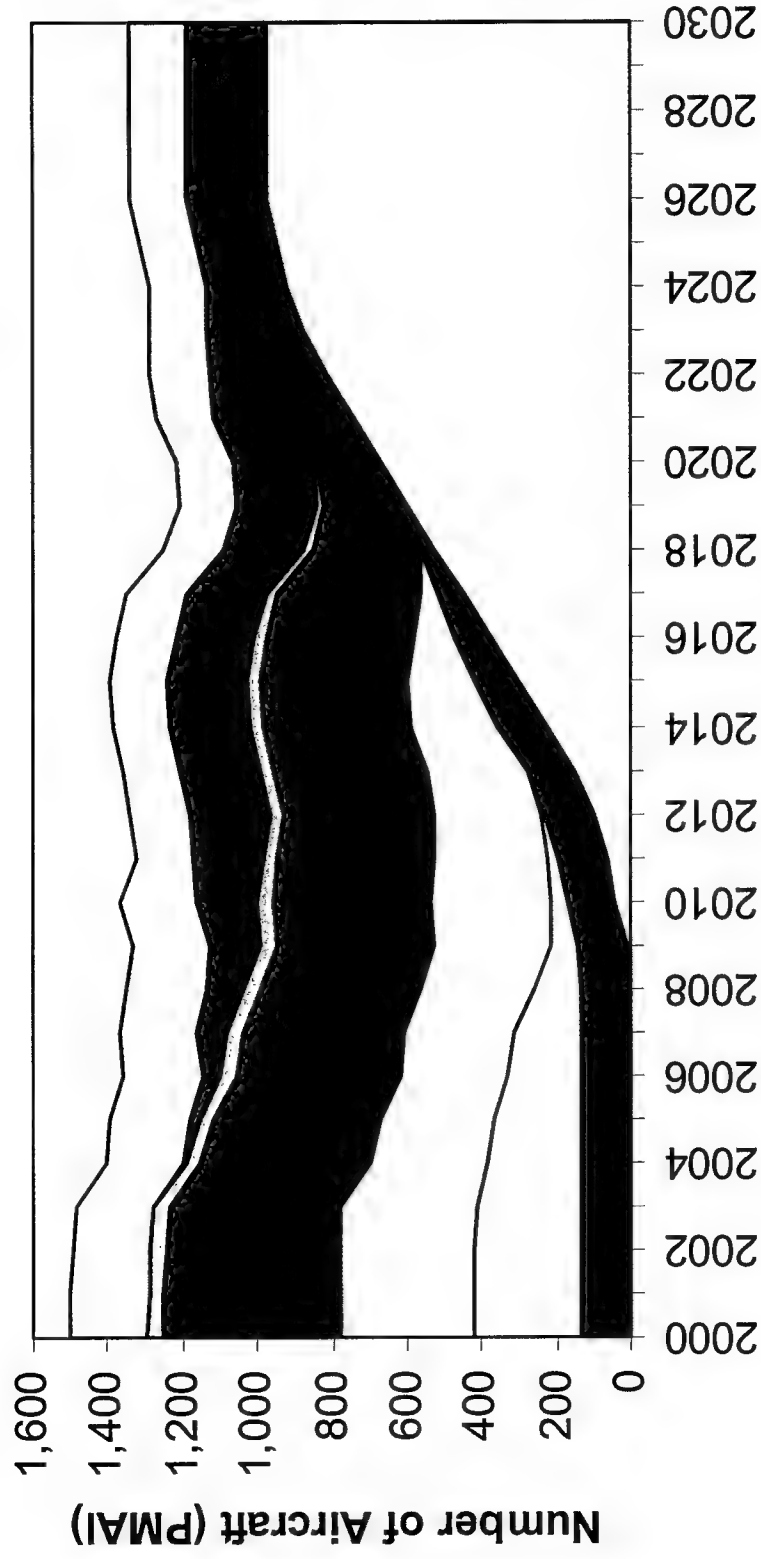
☐ = Study Focus

* Other aircraft incidents may be reportable as Class C regardless of damage (e.g., physiological mishaps such as G-induced loss of consciousness or spatial disorientation).

Class-A Mishaps and Aircraft Destruction

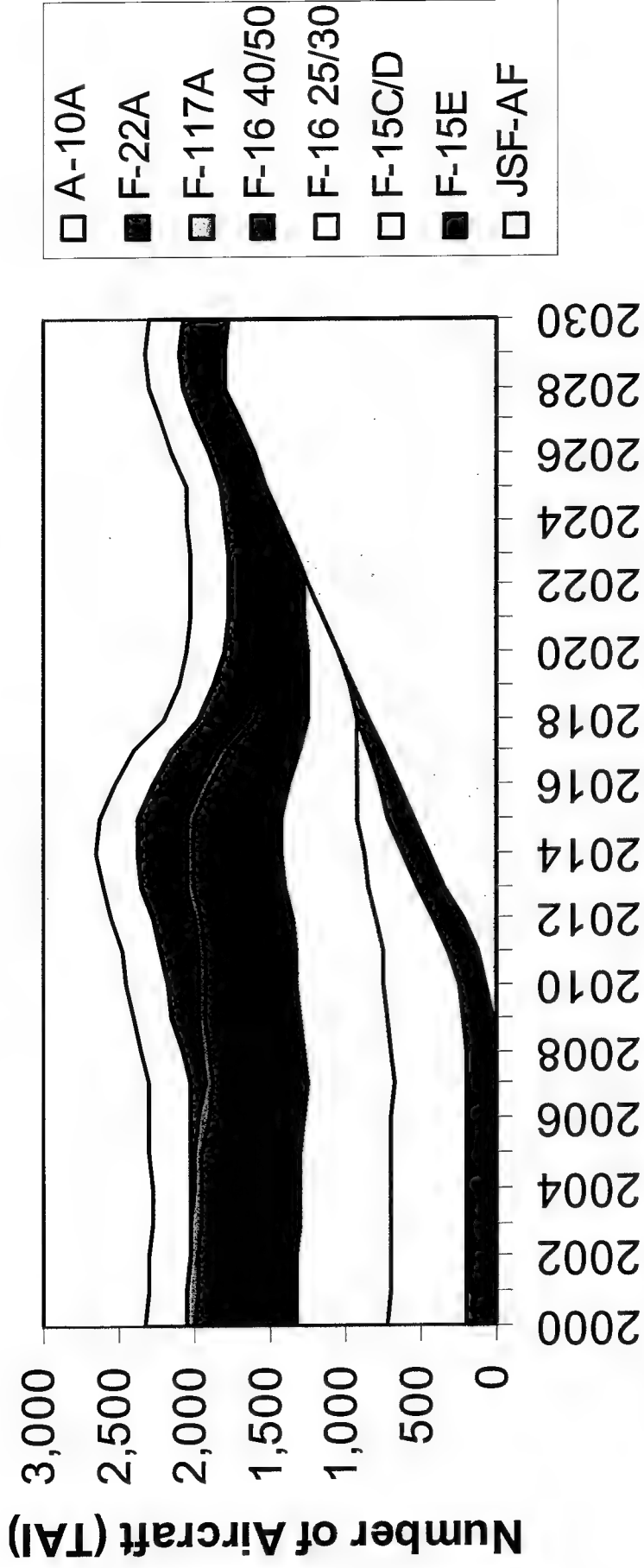


Air Force Primary Mission Aircraft Inventory (PMAI)



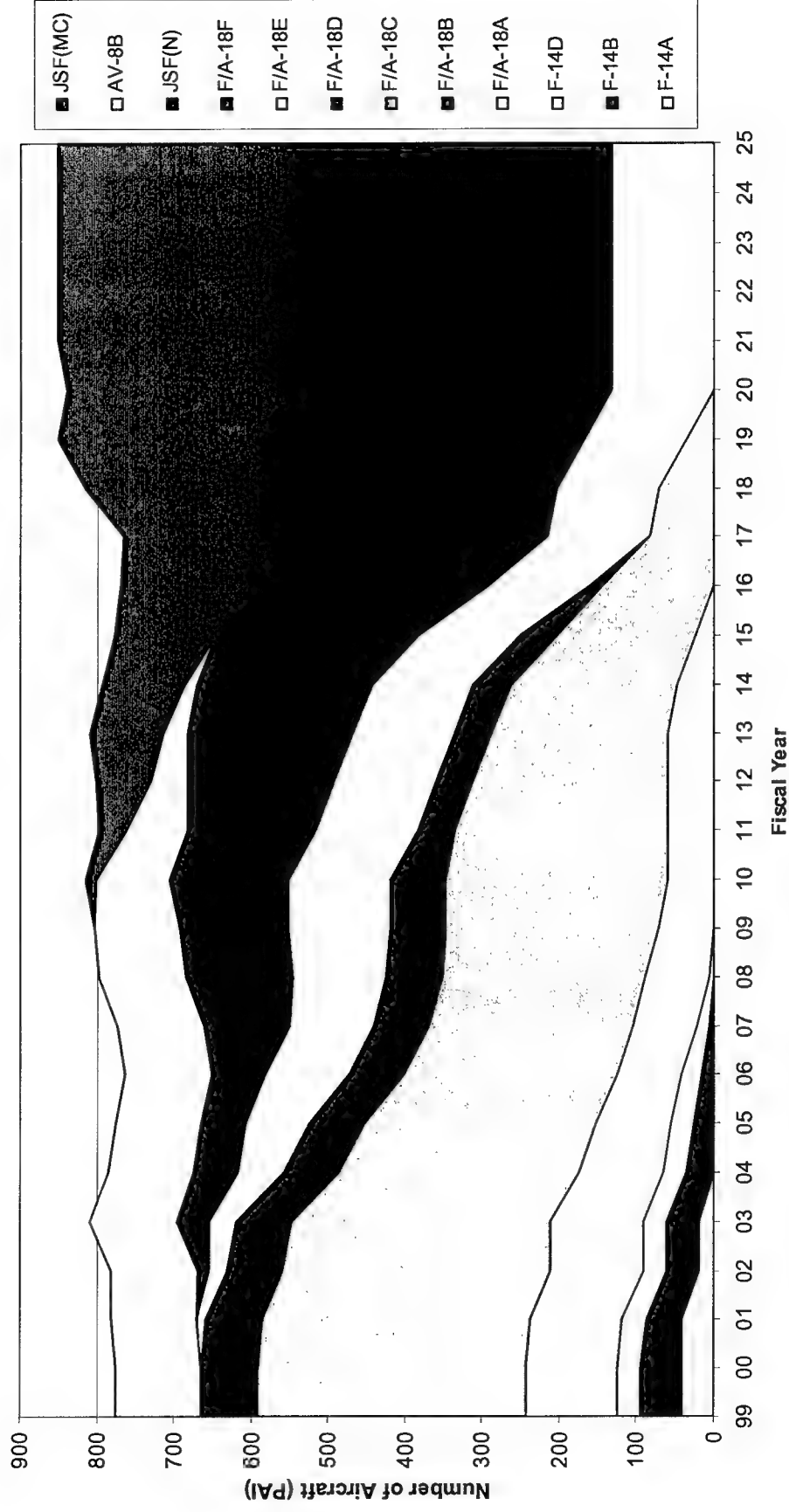
Sources: POM, USAF Modernization Plan, IDA Report R-400.

Air Force Total Aircraft Inventory (TAI)



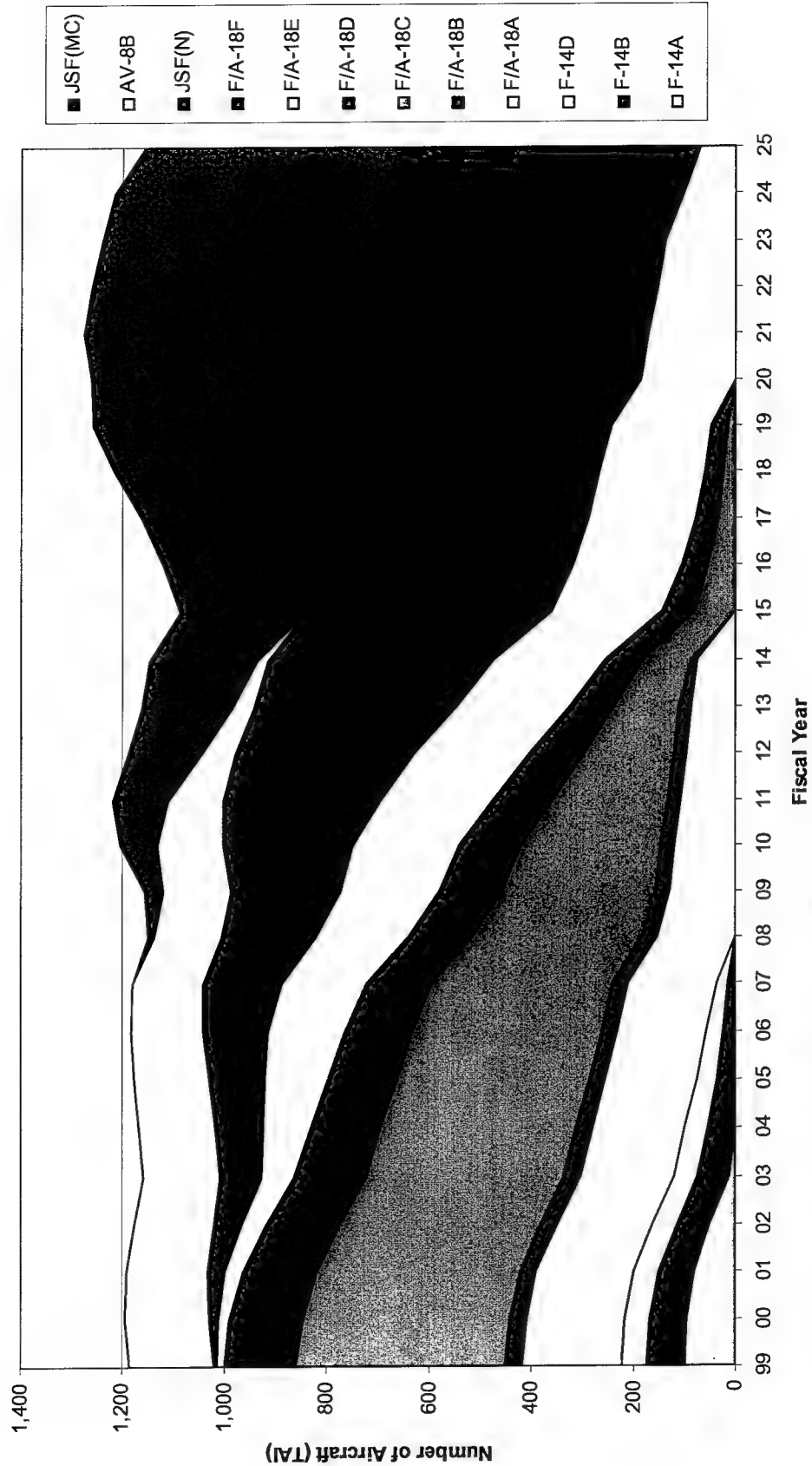
Sources: POM, USAF Modernization Plan, IDA Report R-400.

Navy and Marine Corps Primary Mission Aircraft Inventory (PMAI)



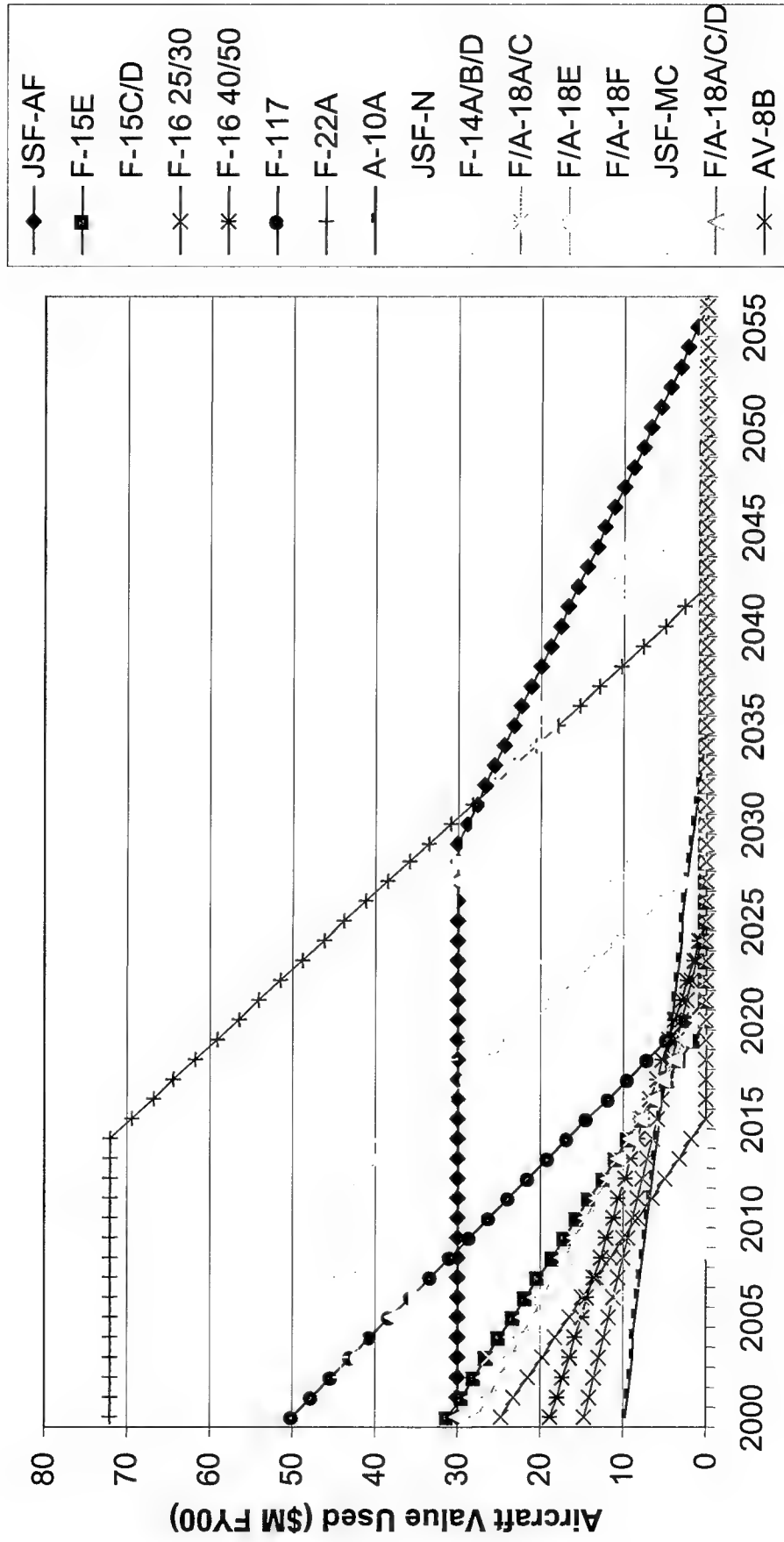
Sources: HQ USMC APP-31, HQ USN N880-G6.

Navy and Marine Corps Total Aircraft Inventory (TAI)



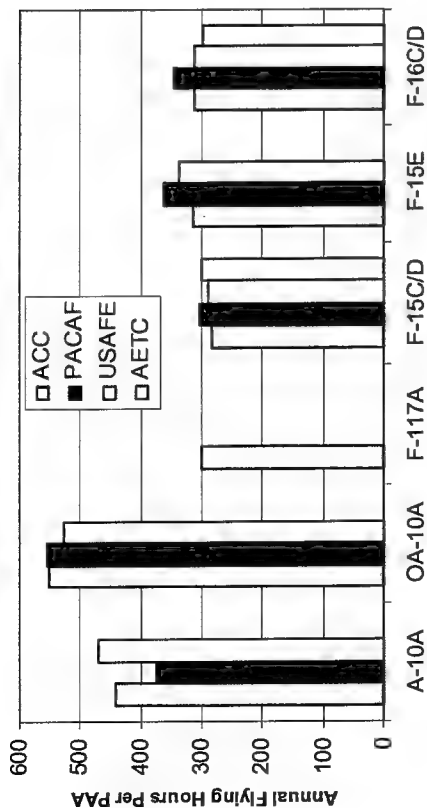
Sources: HQ USMC APP-31, HQ USN N880-G6.

Depreciated Aircraft Values

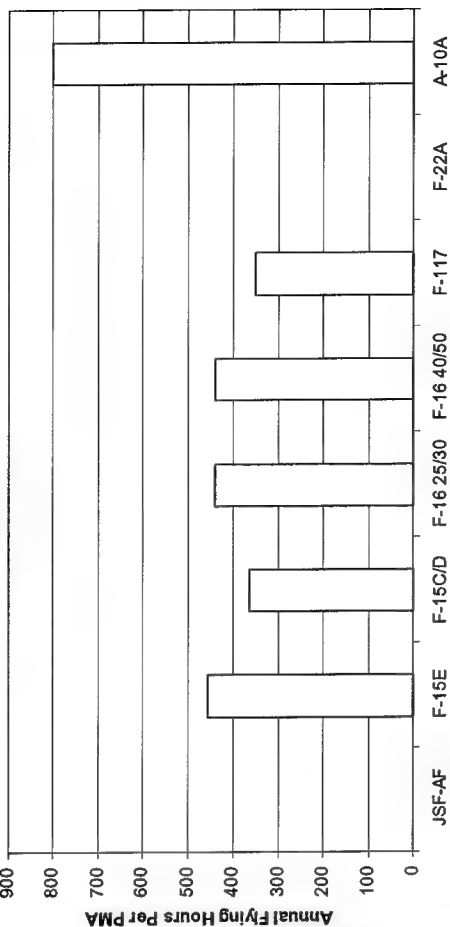


Air Force Flying Hours

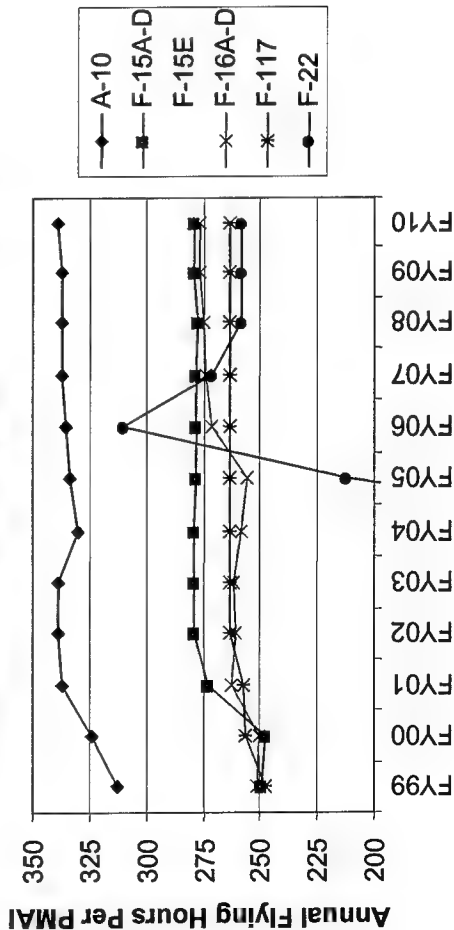
AFI65-503 Planning Factors (per PAA)



1997 Experience (per PMAI)



Programmed (per PMAI)



Fighter Class-A Mishap Rate Overview

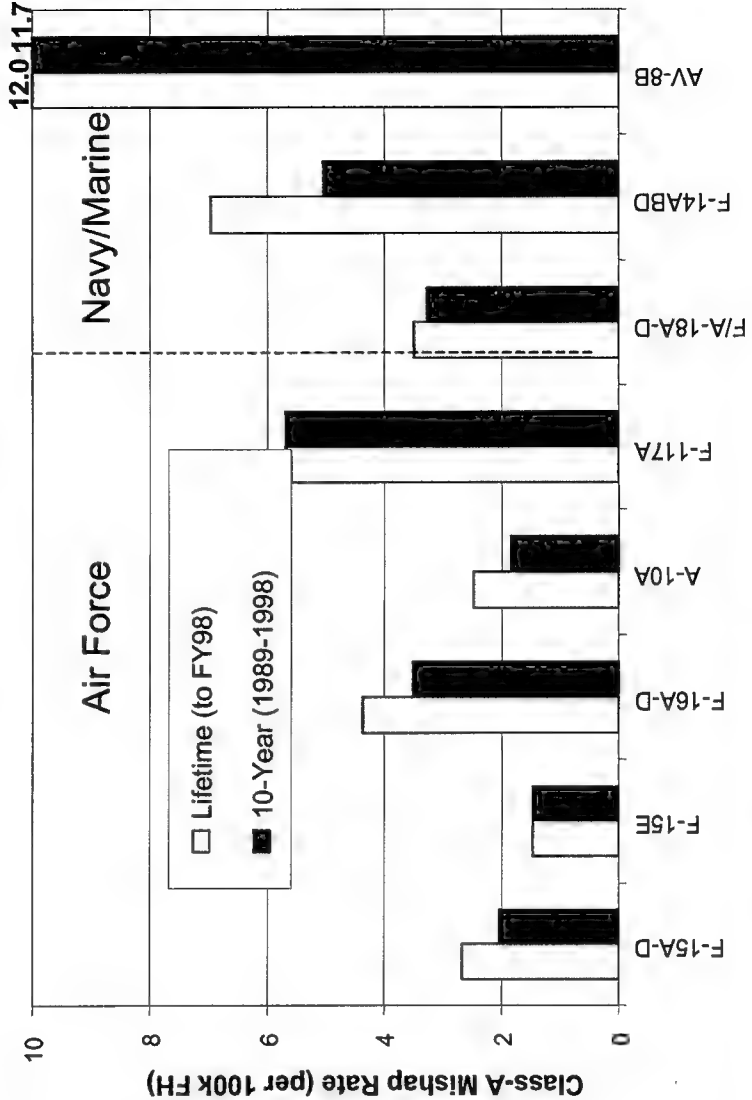
Developmental and Production Aircraft

JSF Variant	Rate with AGCAS (Baseline)	Rate w/o AGCAS (Excursion)
Air Force	2.35	2.90
Navy	3.21	3.83
Marines	5.15	5.80

F-22A	Rate
Air Force (ACC)	1.4-2.1
IDA Estimate (P-3487)	1.90

F/A-18E/F	Rate
IDA Estimate	3.09

Current Aircraft



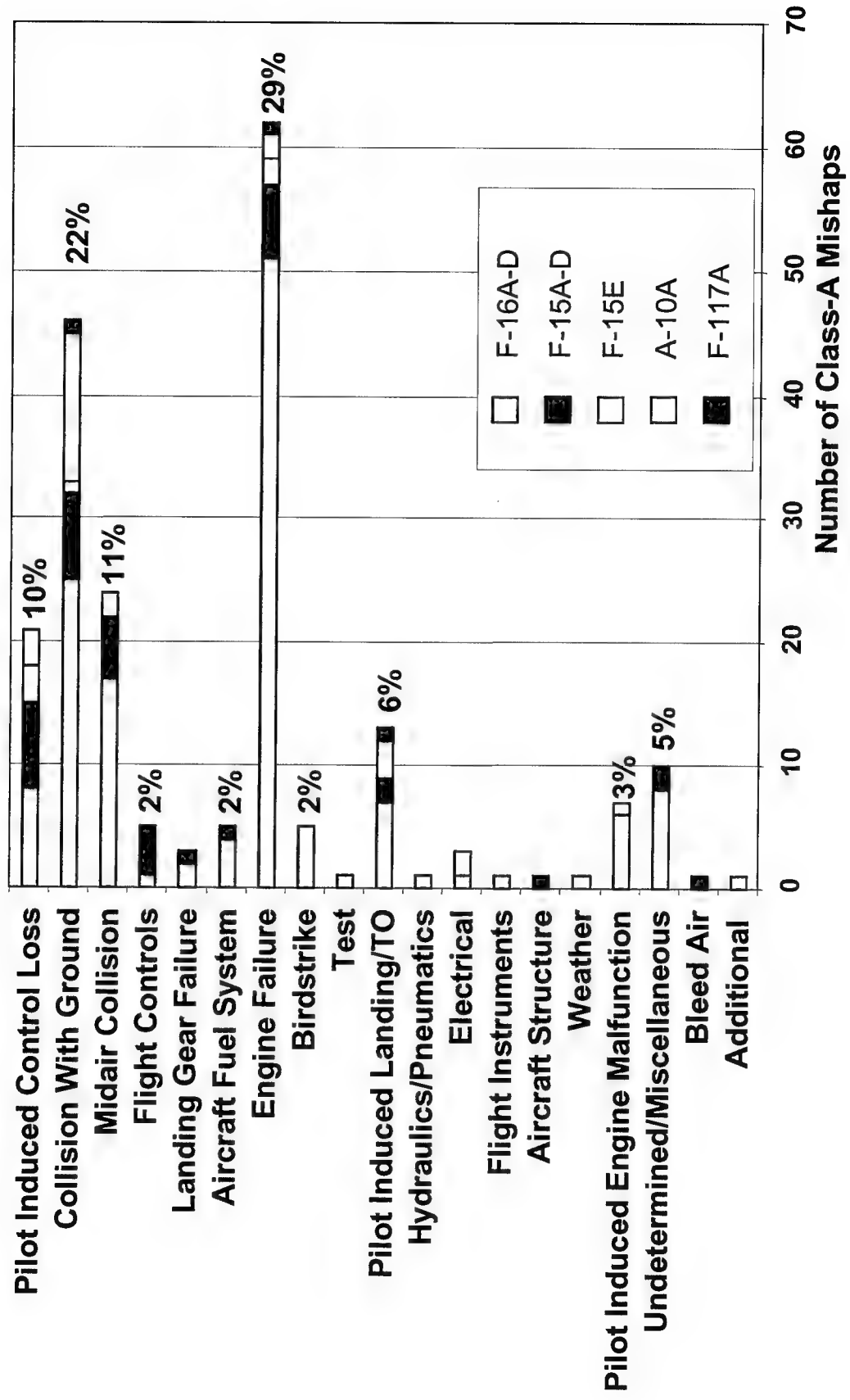
Note: Modeled mishap rates decline over aircraft service lives.

JSF Lifetime Class-A Mishap Rate Estimates (Mishaps/100K FH)

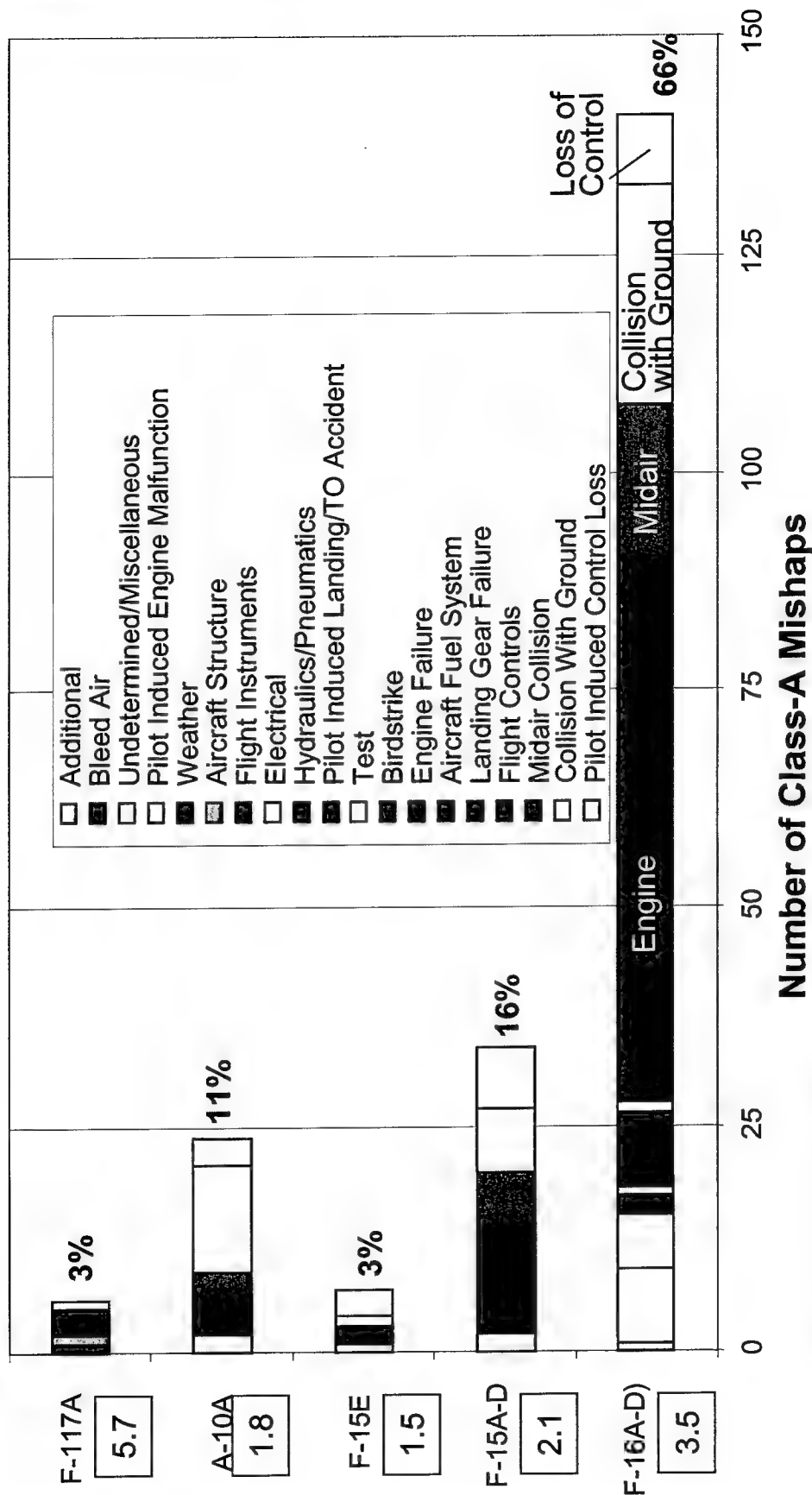
JSF Variant	With AGCAS (Baseline)	Without AGCAS (Excursion)
Air Force	2.35	2.90
Navy	3.21	3.83
Marines	5.15	5.80

Aircraft	Lifetime Rate (Through FY98)
F-16A-D	4.34
F-15E	1.48
A-10A	2.49
F-15A-D	2.70
F-117A	5.69
F/A-18A-D	3.51
F-14A/B/D	6.96
AV-8B	12.00

AF Fighter Class-A Mishap Distribution by Cause 1989-98

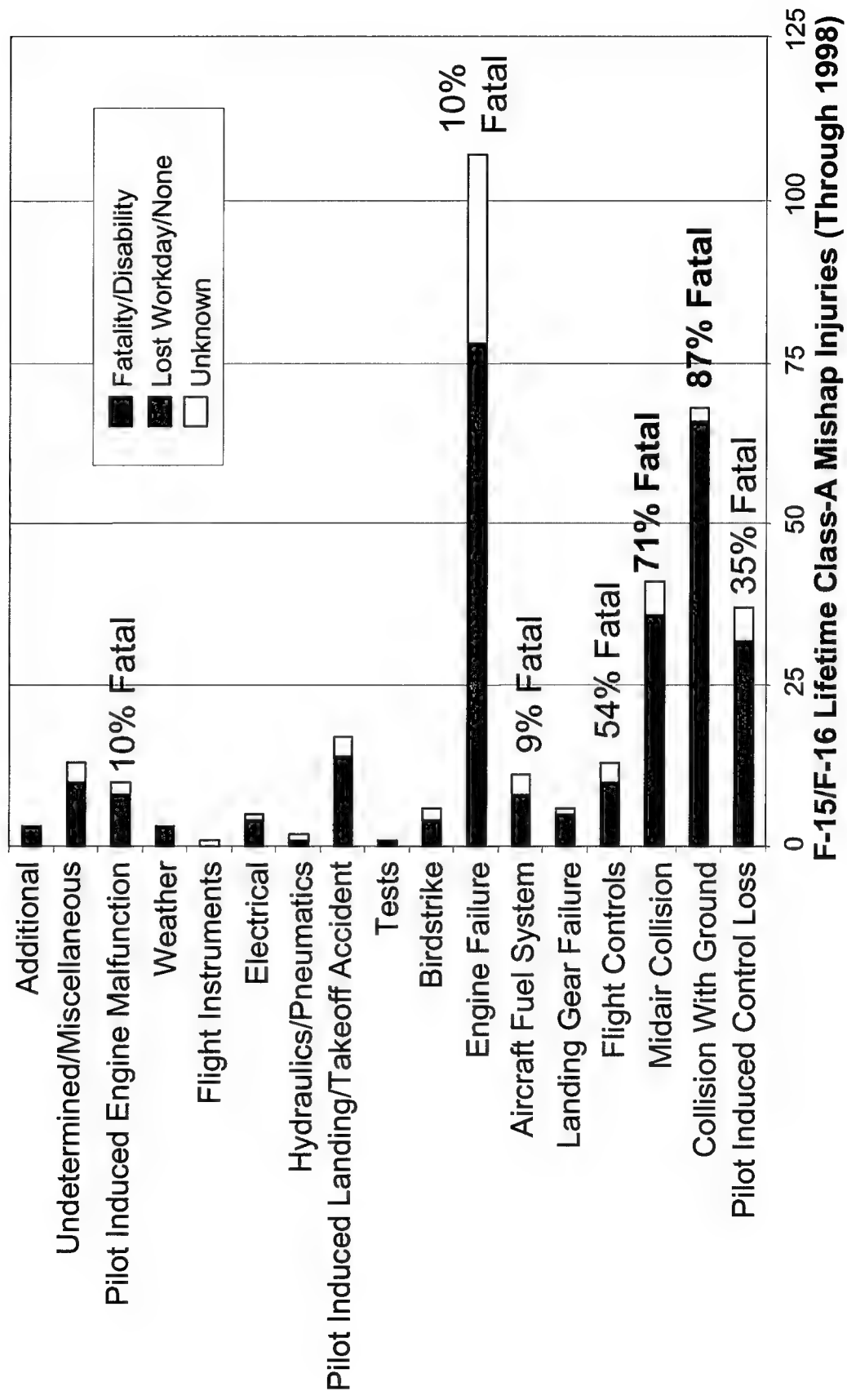


AF Fighter Class-A Mishap Breakdown by Aircraft 1989-98

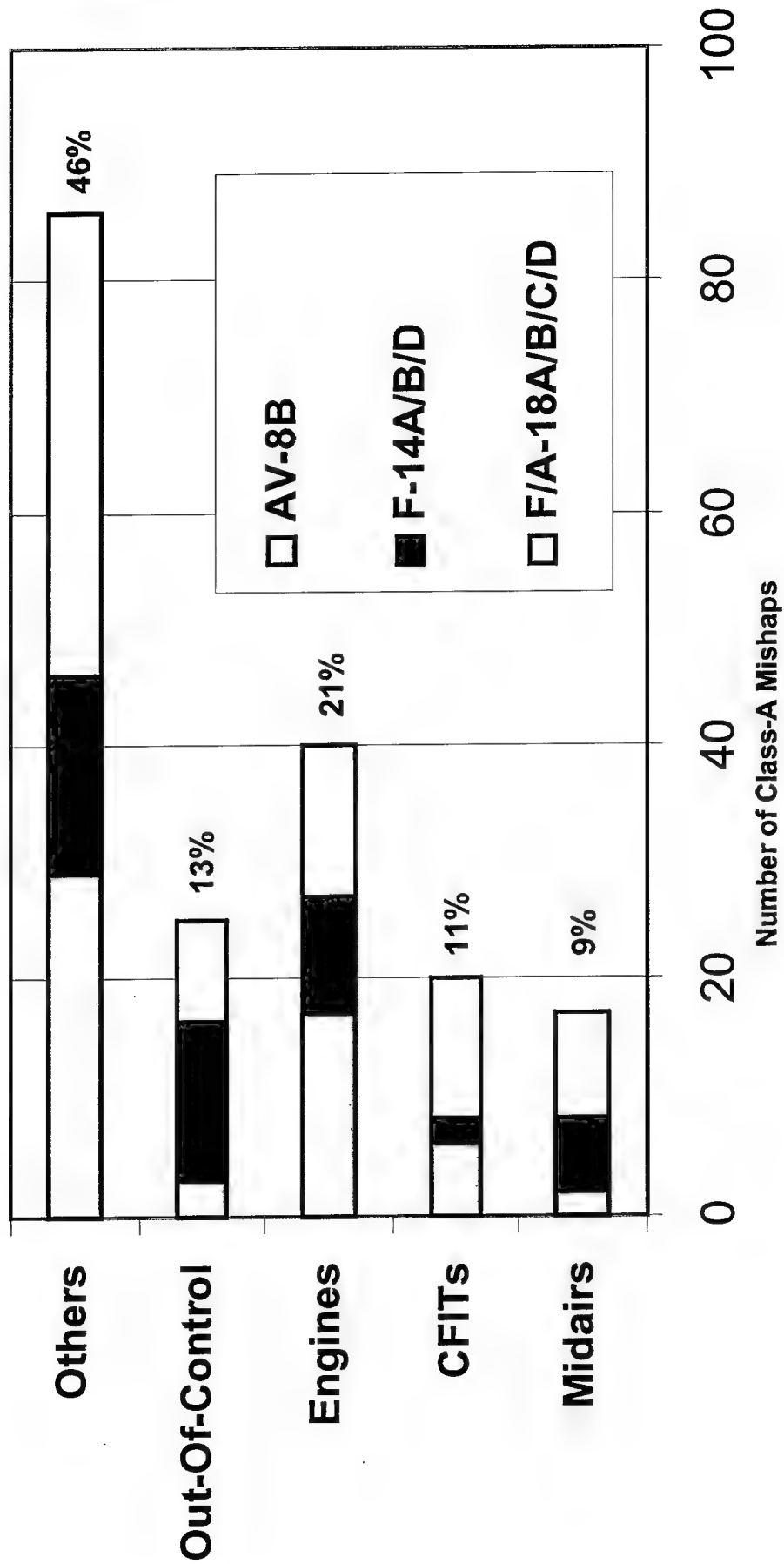


Rate per 100K Flying Hours

F-15/F-16 Injuries By Class-A Mishap Category



USN/USMC Fighter Class-A Mishap Distribution: 1989-1998



Preliminary Mishap Mitigation Applicability

Safety Concept Applicable to Fighters	Mishap Type Potentially Mitigated						
	Pilot Induced Control Loss	Collision With Ground	Midair Collision	Engine Failure	Pilot Induced TO/LD Accident	Pilot Induced Engine Malfunction	Others
	Auto Gnd Collision Avoidance Sys (AGCAS)	x	X				
	Passive Predictive Gnd CAS (PGCAS)	x	x				
	Emergency Parafoil Recovery Sys (EPRS)	X			X	X	X
	Midair Collision Avoidance Sys (MCAS)			X			
	Engine Enhancements (Based on ECIP)				X	X	
	Pilot Activated Auto Recovery Sys (PAARS)	X	X				
	Global Air Traffic Management (GATM)			x			
	Mitigates crew fatality in unrecoverable situation						
Automatic Pilot Ejection (APE)					X		
Automatic Takeoff and Landing System							
Auto Dep Surveillance-Broadcast (ADS-B)		x	X		x		
Smart Cockpit/Virtual Copilot System (VCS)	x	x	x		x	x	

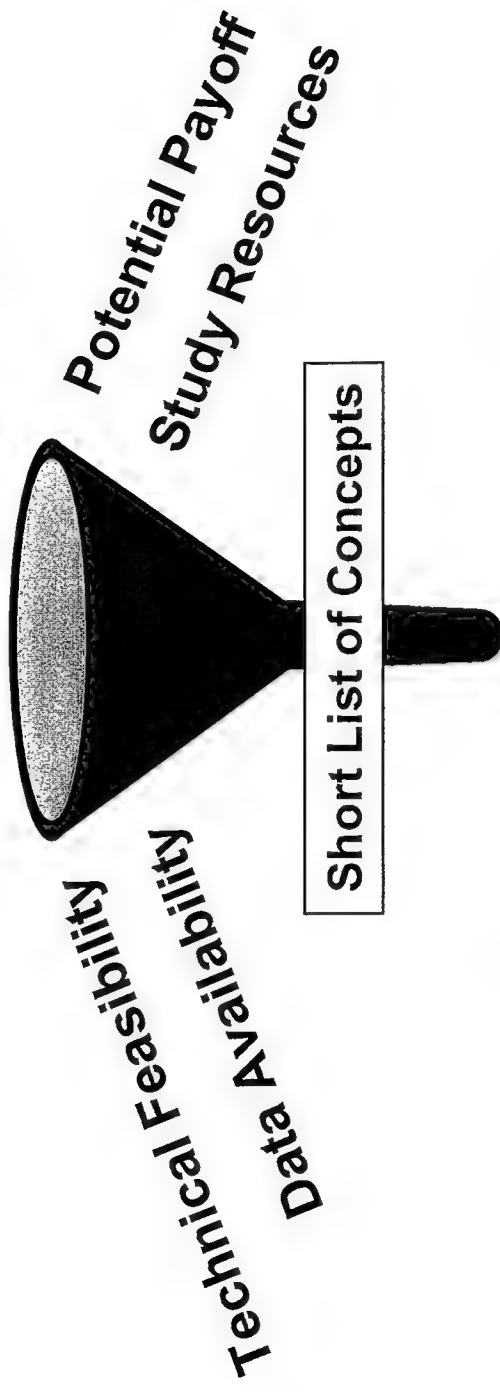
X High level of mitigation anticipated
 x Medium level of mitigation anticipated
 x Low level of mitigation anticipated

☐ AF categories encompassing 81% of current fighter lifetime Class-A mishaps.

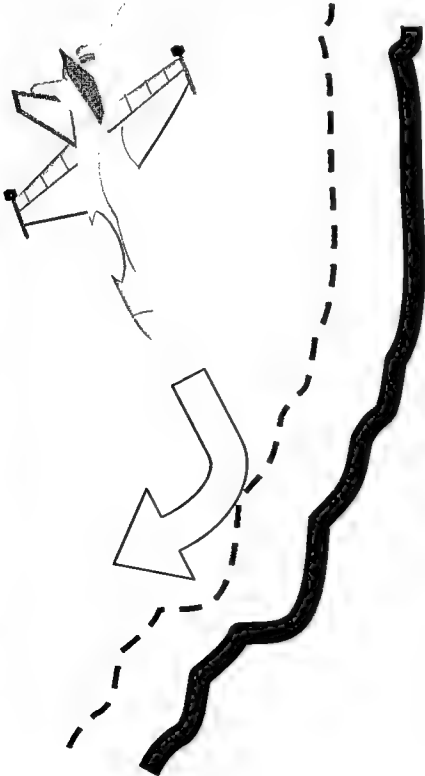
Concept Filtering Process

Technological and Human Factor Ideas

- DSB Recommendations
- Operator/Safety Center Inputs
- Sponsor Suggestions
- Other Experts/Literature Search

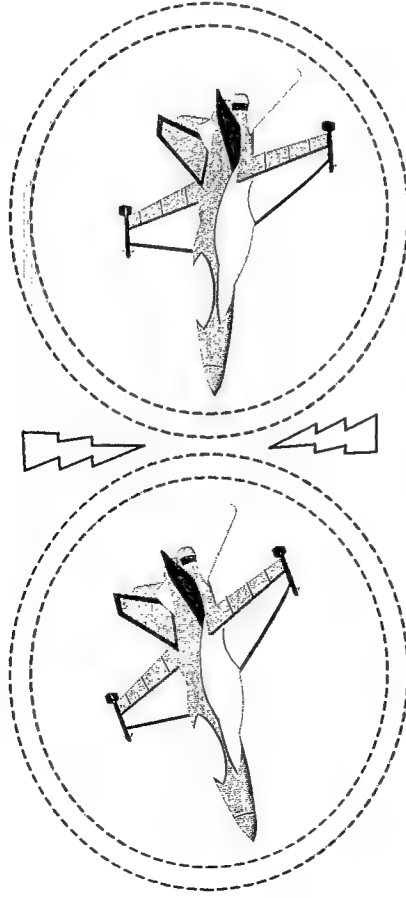


Automatic Ground Collision Avoidance System (AGCAS)

<u>SYSTEM ILLUSTRATION</u>	<u>DESCRIPTION AND STATUS</u>
	<ul style="list-style-type: none"> • Autopilot activation and automatic flyup upon determination of impending impact with ground or water • Flight tested on F-16 AFTI and F-16D. Under consideration for F-22, F-16; planned for Swedish Gripen; JSF threshold requirement
<u>POTENTIAL SAFETY IMPACT</u>	<u>IMPLEMENTATION ISSUES</u>
<ul style="list-style-type: none"> • Reduction in Class-A mishaps due to CFIT resulting from lack of situational awareness or spatial disorientation and collision with ground resulting from pilot GLOC 	<ul style="list-style-type: none"> • Cost <ul style="list-style-type: none"> – EMD – Aircraft integration (aircraft numbers, flight control system) – O&S cost • Operator Resistance <ul style="list-style-type: none"> – False Alarm Rate

Midair Collision Avoidance System (MCAS)

SYSTEM ILLUSTRATION



DESCRIPTION AND STATUS

- Aural/visual warning or automatic breakaway upon determination of impending impact with another aircraft (of similar type)
- Conceptual; included in NAWC ANGEL Program, under study by AFRL (program start in FY00)


POTENTIAL SAFETY IMPACT

- Reduction in Class-A mishaps due to midair collision of similar type aircraft

IMPLEMENTATION ISSUES

- EMD cost
- Aircraft integration cost
 - Aircraft number, flight control system
- O&S cost
- Operator resistance

Emergency Parafoil Recovery System (EPRS)

<div data-bbox="412 1329 461 1890"> <u>SYSTEM ILLUSTRATION</u> </div> <div data-bbox="469 1236 899 1990">  </div>	<div data-bbox="412 359 461 1016"> <u>DESCRIPTION AND STATUS</u> </div> <div data-bbox="485 186 899 1094"> <ul style="list-style-type: none"> • Manual or automatic parafoil deployment for softer impact when aircraft is unrecoverable • Conceptual for fighters. Analogous system planned on NASA X-38 CRV. Simple parachutes used on some light civil aircraft. </div>
<div data-bbox="954 1266 1003 1940"> <u>POTENTIAL SAFETY IMPACT</u> </div> <div data-bbox="1044 1163 1386 2049"> <ul style="list-style-type: none"> • Reduction in Class-A mishaps (where aircraft is destroyed) due to engine failures or malfunctions (inherent and pilot induced), fuel system problems, and flight control loss (inherent or pilot induced) </div>	<div data-bbox="954 352 1003 982"> <u>IMPLEMENTATION ISSUES</u> </div> <div data-bbox="1019 249 1403 1110"> <ul style="list-style-type: none"> • Cost <ul style="list-style-type: none"> – EMD, Aircraft Integration, O&S • Weight and drag <ul style="list-style-type: none"> – Removable for combat • Operator Resistance <ul style="list-style-type: none"> – Giggle Factor – Training burden </div>

EPRS Installation Penalties (1)

Basic Penalties with EPRS Installed:

- **Weight**
- **Volume (Drag)**

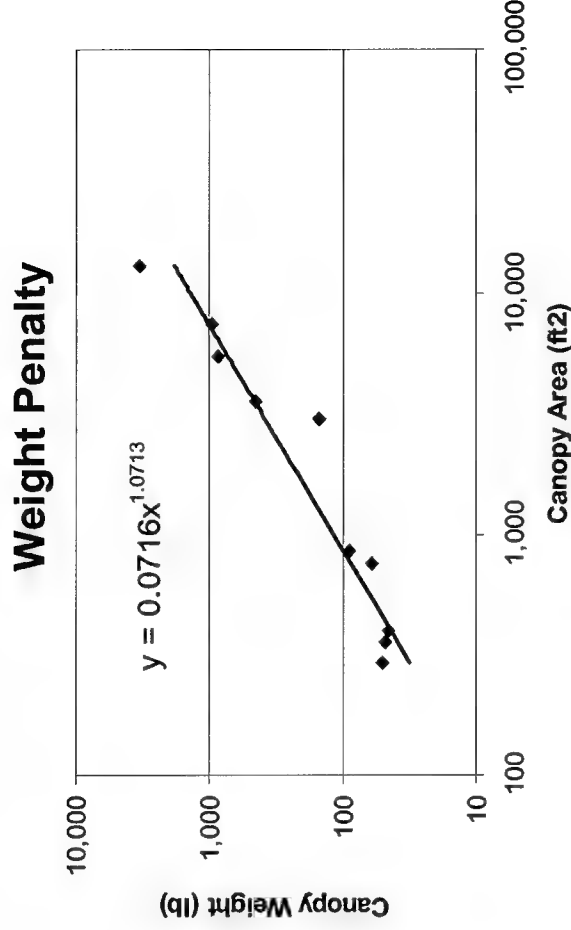
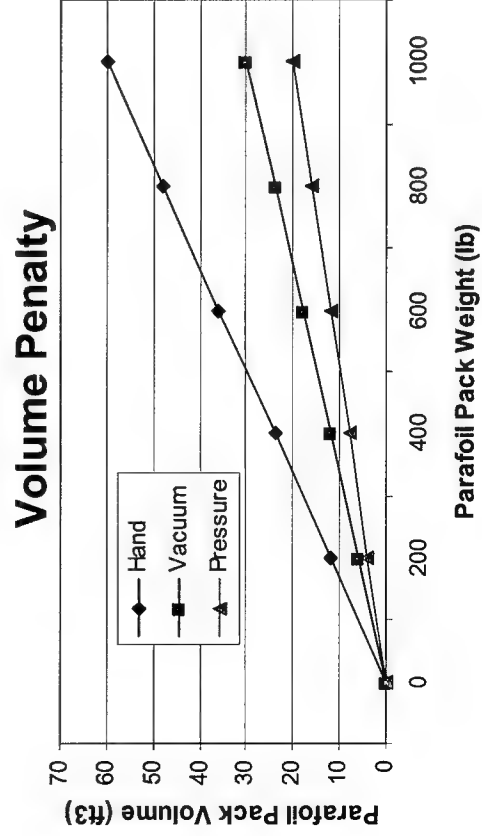
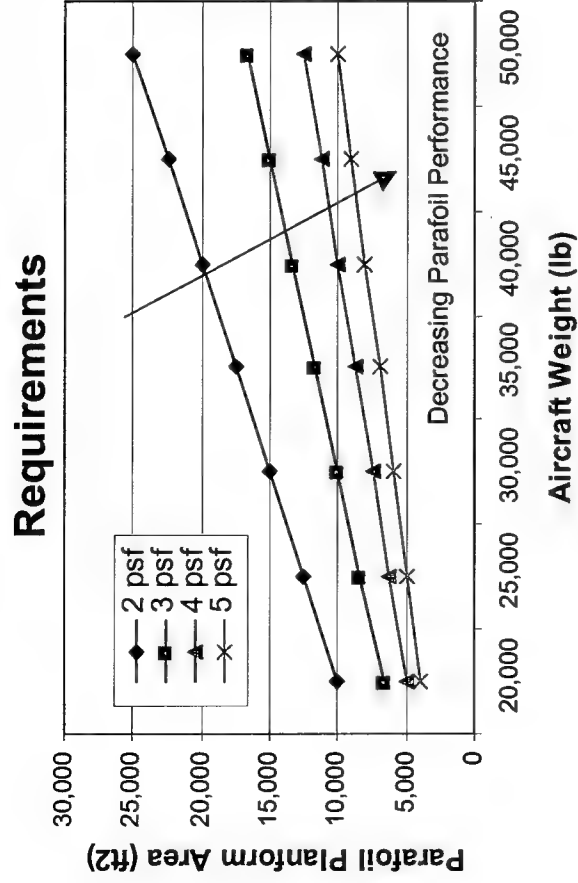


Resulting Aircraft Performance Penalties:

- **Range/Payload**
- **Maneuverability**
- **Flight Envelope**

Penalties can be mitigated with removable system (for combat)

EPRS Installation Penalties (2)



Magnitude of penalties dictates removable system for combat

EPRS Installation Penalties (3)

F-16 BLK30/40/50 Standard



F-16 BLK60 With Conformal Tanks

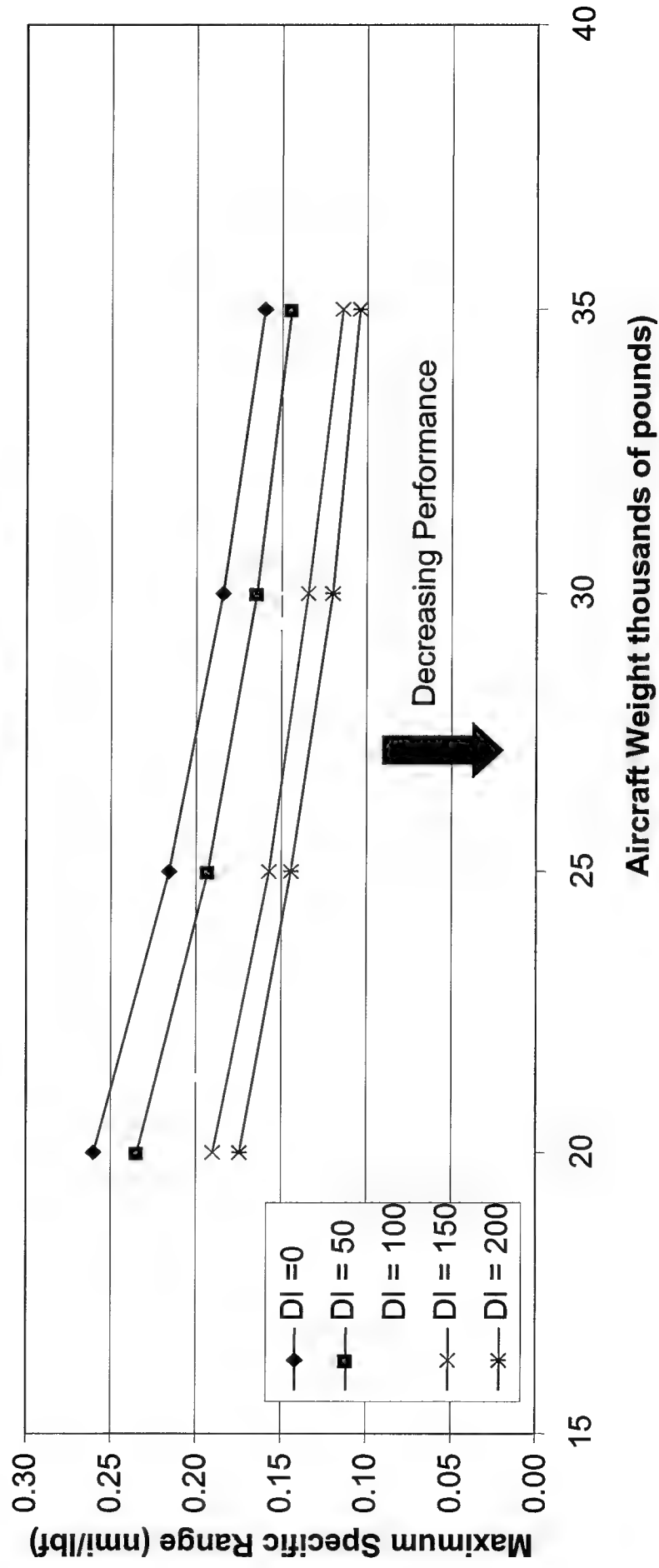


Conformal Fuel Tanks on F-16 BLK60

- Fuel Volume = 63 ft³ (467 gal)
- Fuel Weight = 3,128 lb
- Drag Index = TBD

EPRS Installation Penalties (4)

F-16C SPECIFIC RANGE TREND



EPRS Installation Penalties (5)

Boeing JSF Demonstrator



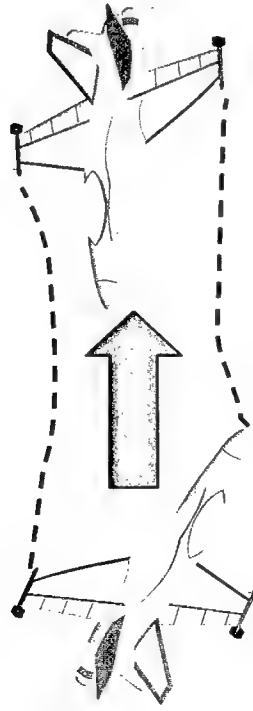
Lockheed JSF Demonstrator



EPRS Installation Penalty on JSF?

Pilot Activated Automatic Recovery System (PAAARS)

SYSTEM ILLUSTRATION



DESCRIPTION AND STATUS

- Automatic recovery to stable attitude (wings level with slight climb) upon pilot activation
- System installed on F-117 in early 1990s.
- Optional add-on to AGCAS

POTENTIAL SAFETY IMPACT

- Reduction in Class-A mishaps due to CFIT resulting from spatial disorientation

IMPLEMENTATION ISSUES

- EMD cost
- Aircraft integration cost
 - Aircraft number, flight control system
- O&S cost

Aircraft and Aircrew Saved Rankings

Safety Systems on New Aircraft

Ranking	Aircraft	Aircrews
1	JSF-AF	JSF-AF*
2	JSF-AF*	
3	JSF-MC	JSF-MC*
4		JSF-N*
5	JSF-N	
6	JSF-MC*	
7	JSF-N*	JSF-AF
8		JSF-AF
9		
10		F-22A

EPRS



AGCAS

PAARS

* - Indicates ranking if AGCAS is deleted from JSF baseline; full AGCAS would incorporate PAARS feature.

Safety Systems on Current or Production Aircraft

Ranking	Aircraft	Aircrews
1	A-10A	F/A-18E/F
2	F/A-18E/F	A-10A
3		
4	F-16 Blk 40/50	F-16 Blk 40/50
5	F-16 Blk 40/50	F/A-18A/D
6	F/A-18E/F	F/A-18E/F
7	F/A-18A/D	
8		F/A-18E/F
9	F-16 Blk 25/30	
10		F-16 Blk 25/30

- Although JSF dominates rankings, A-10, F/A-18E/F, F-16C/D and F-22A alternatives also have significant potential for saving aircraft and crews
- If not included in JSF baseline, AGCAS on JSF becomes a top option

Cost of F-15/F-16 Pilot Replacement

1990-99 AF Safety Center statistics show average fighter pilot Class-A fatality was a 32-year-old 0-3 with 870 fighter hours and 2000 hours of total flying time

Costs:	<u>F-16</u>	<u>F-15C</u>	<u>F-15E</u>
Flight Screening Program	23,000		
UPT -- Primary	270,000		
UPT -- Bomber/Fighter	435,000		
Introduction to Fighter Fundamentals	<u>122,000</u>		
Subtotal:	850,000	850,000	850,000
Basic Fighter Course (50 hours)	<u>1,200,000</u>	<u>1,875,000</u>	<u>1,875,000</u>
Experience: Cost/Flying Hour	8,500	13,500	15,000
x 820 Hours	<u>6,970,000</u>	<u>11,070,000</u>	<u>12,300,000</u>
Total:	9,020,000	13,795,000	15,025,000
Percent of Total Fatalities	65	31	4

\$10,740,000

**Average Replacement Cost
(for Training and Fighter Experience Only)**

Sources: Fatalities, AF Safety Center; Costs, Internal IDA Analysis (FY00 rounded to nearest \$1,000).

Value of Mishaps Averted and Net Benefit Rankings

Safety Systems on Current or Production Aircraft

Rank	\$ Loss Averted	Total \$ Net Benefit
1	JSF-AF	JSF-AF*
2	JSF-AF*	JSF-N*
3	JSF-MC	JSF-MC*
4		
5	JSF-N	JSF-MC
6	JSF-MC*	F-22A
7	JSF-N*	
8		
9		
10		F-22A

EPRS



AGCAS

PAARS

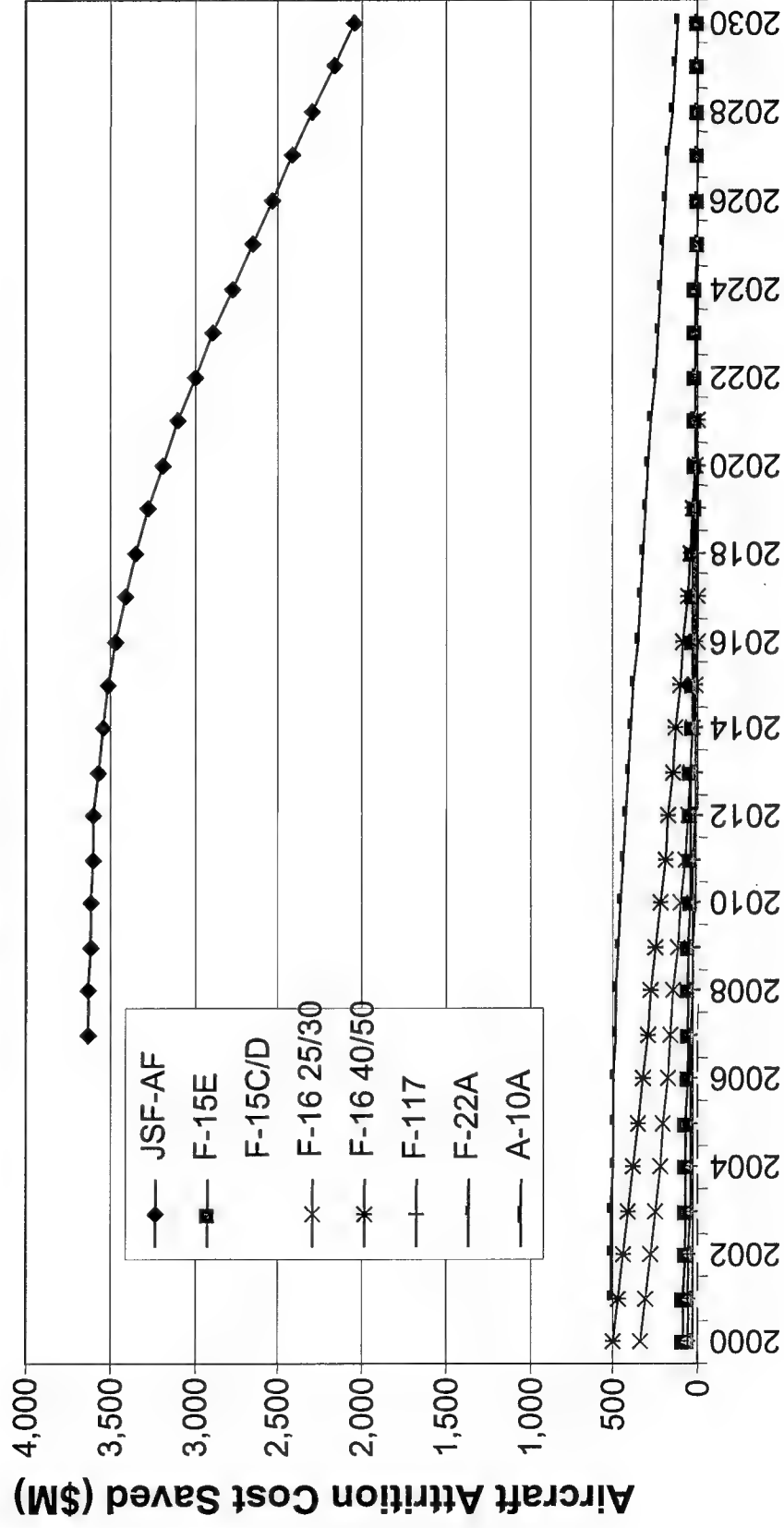
Rank	\$ Loss Averted	Total \$ Net Benefit
1	F/A-18E/F	F/A-18E/F
2		
3	F/A-18E/F	F/A-18E/F
4	A-10A	F-16 BIK 40/50
5	F-16 40/50	F/A-18A/D
6	F-16 40/50	AV-8
7	F/A-18A/D	AV-8
8	F/A-18E/F	F-16 BIK 40/50
9		F-117
10		A-10A

* - Indicates ranking if AGCAS is deleted from JSF baseline; full AGCAS would incorporate PAARS feature.

- Positive net benefit for some options involving JSF, F-22, and F/A-18E/F
- If AGCAS is not in JSF baseline, JSF/AGCAS ranks 1- 3 on net benefit list
- Highest ranked near-term options are AGCAS on F/A-18 and F-16C/D

Maximum AF Attrition Costs Saved: Engine Modifications

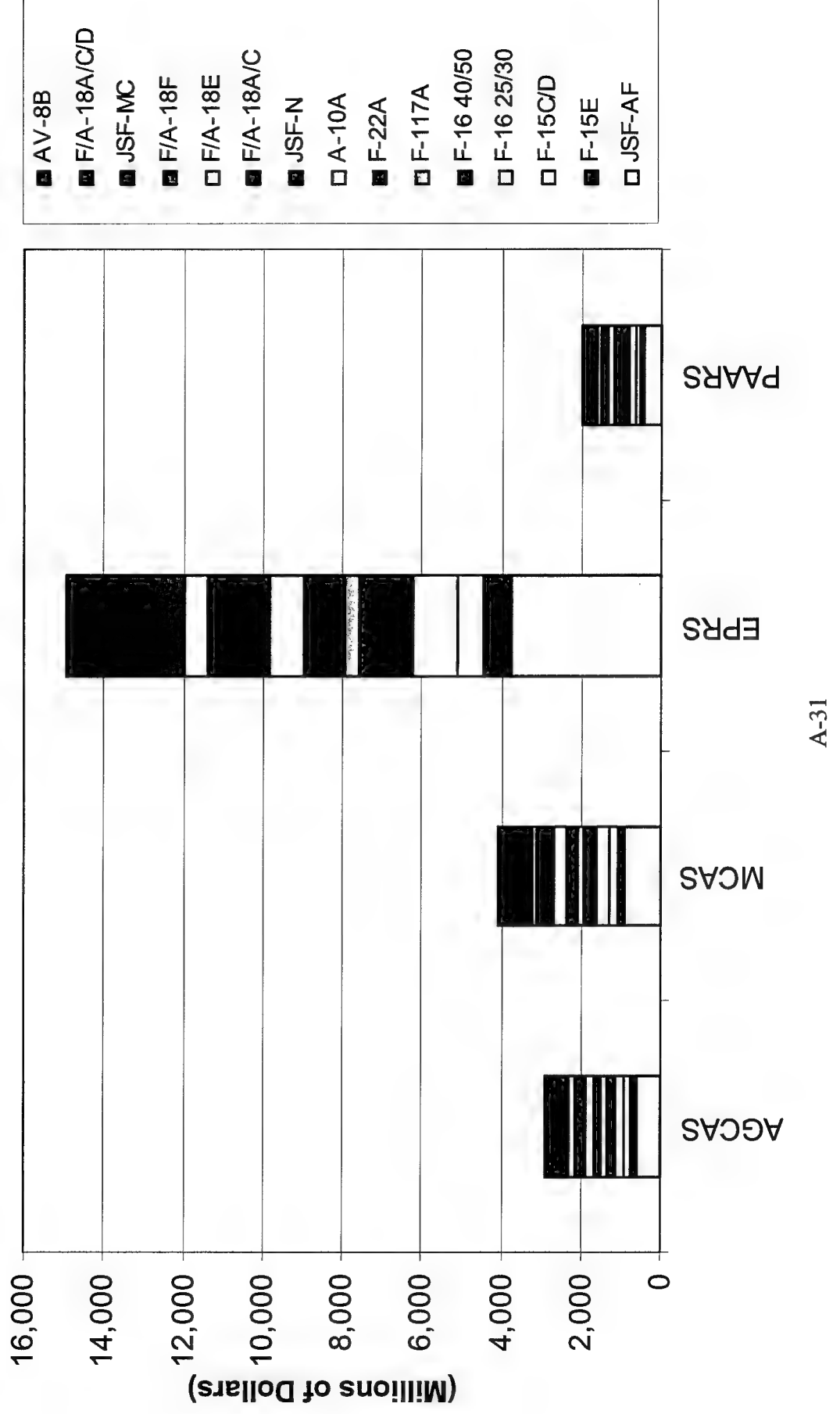
No Class-A Mishaps Due to Engine Failures



Cost Ground Rules

- **Analysis accomplished in FY00 dollars**
- **Costs discounted using appropriate discount rate**
- **Flyaway cost used as baseline; asset value of aircraft adjusted for remaining life, as well as to investigate other cost sensitivities**

Safety System Implementation Cost Estimates (\$M FY00)



AGCAS on F-16C

Analyses Comparison

SAF/AQP Brief: 18 May 99

- **Program Costs (FY00)**
 - \$443M (O&S not included)
- **Schedule**
 - EMD: FY01-FY06
 - Acquisition: FY06-FY10
- **Aircraft Service Life**
 - Ending in FY21
- **Aircraft/Aircrew Attrition**
 - 218/62 total remaining
 - 19/16 saved when fielded by FY10
- **Aircraft/Crew Values**
 - \$28.8M (undepreciated)/\$1.1M

IDA Aviation Safety Study

- **Total Program Costs (FY00)**
 - \$458M (includes O&S)
- **Schedule**
 - EMD: FY02-FY07
 - Acquisition: FY05-FY13
- **Aircraft Service Life**
 - Ending in FY24
- **Aircraft/Aircrew Attrition**
 - 152/41 total remaining
 - 18/14 saved when fielded in FY05
 - 10/8 saved when fielded in FY10
- **Aircraft/Crew/Other Values**
 - \$15-19M (AFI65-503)/\$10M/\$1M

SAF/AQP: positive monetary net benefit; **IDA:** marginal monetary net benefit for F-16, but recommended first step for implementing AGCAS in fighter fleet

Appendix B

GLOSSARY

GLOSSARY

A/C	Aircraft				Full Operational Capability
ADS-B	Automatic Dependent Surveillance-Broadcast		FOC		Fiscal Year
AF	Air Force		FY		
AFI	Air Force Instruction				
AFRL	Air Force Research Laboratory				
AGCAS	Automatic Ground Collision Avoidance System		GLOC		G-Induced Loss of Consciousness
APES	Automatic Pilot Ejection System		GPS		Global Positioning System
			IDA		Institute for Defense Analyses
			IFDL		Intra Flight Data Link
			IOC		Initial Operating Capability
B	Billion				
CFIT	Controlled Flight Into Terrain		JORD		Joint Operational Requirements Document
CRV	Crew Return Vehicle		JSF		Joint Strike Fighter
			JTIDS		Joint Tactical Information Distribution System
DoD	Department of Defense				
DUSD(ES)	Deputy Under Secretary of Defense (Environmental Security)				
			M		Million
			MI		Maintenance Induced
EMD	Engineering and Manufacturing Development		MCAS		Midair Collision Avoidance System
EPRS	Emergency Parafail/Recovery System		MEMS		Micro-Electric Mechanical System
			MI		Maintenance Induced
			MOE		Measure of Effectiveness

GLOSSARY

NASA	National Aeronautics and Space Administration	TAI	Total Aircraft Inventory
NAWC	Naval Air Warfare Center	TAWS	Terrain Awareness Warning System
O&S	Operations and Support	USAF	United State Air Force
PAARS	Pilot Activated Automatic Recovery System	UPT	Undergraduate Pilot Training
PMAI	Primary Mission Aircraft Inventory	USMC	United States Marine Corps
POM	Program Objective Memorandum	USN	United States Navy
R&D	Research and Development	VCS	Virtual Copilot System
SAF/AQ	Assistant Secretary of the Air Force for Acquisition	VTOL	Vertical Take Off and Landing

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